MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LXXX. APRIL 9, 1920. No. 6

Sir F. W. DYSON, F.R.S., VICE-PRESIDENT, in the Chair.

Leonard Berger Benny, M.A., Mathematical Department, University College, Exeter;
Violet Mary Common, 62 Ranelagh Road, Ealing, W. 5;
J. P. Henderson, M.A., Dominion Observatory, Ottawa, Canada;
Donald William Horner, F.R.Met.Soc., Glendale, Tower Park, Moretonhampstead, Devon;
Harold Lee Parker Jolly, M.A., Ordnance Survey Office, Southampton;
Elizabeth Isis Kent (*née* Pogson), "Velindre," 213 Holdenhurst Road, Bournemouth;
William Reginald Kirkwood, Stoke House, Seaford, Sussex;
Henry Lowery, B.Sc. (Lond.), F.R.Met.Soc., 18 Montreal Street, Cleator Moor, Cumberland; and
J. Horace Reeves, M.A., M.B.E. (Military), 6 Penywern Road, Earl's Court, S.W.,

were balloted for and duly elected Fellows of the Society.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended:—

Captain George Frederick Dickens, D.S.C., Lieut. R.N.R., 24 Southside, Weston-super-Mare (proposed by E. Fawcett White);
Walter Gornold, 3 Medina Villas, Hove, Sussex (proposed by Edmund J. Spitta);
R. Leetham Jones, M.A. (Cantab.), 11 Eardley Crescent, Earl's Court, London, S.W. 5 (proposed by Fred. J. W. Crowe);

Gerald Merton, M.A. (Cantab.), M.C., Slopes, Woldingham, Surrey (proposed by W. G. de W. Mitchell);

J. de Mendizábal Tamborrel, Ingénieur Géographe, Sociedad Alzate, Mexico D.F., Mexico (proposed by E. B. Knobel); and

Prof. J. Proudman, Tidal Institute, The University, Liverpool (proposed by Sir F. W. Dyson).

Sixty-two presents were announced as having been received since the last Meeting, including, amongst others:—

Four nine-inch mirrors formerly belonging to the late William Lassell, and a box of his MS. books of Observations, presented by A. Lassell, Esq.

The Chairman also announced that Mrs. H. J. Watson had presented to the Society the sum of £300 in memory of her late husband, Col. H. J. Watson, and that it had been arranged that the interest should be used in the purchase of books for the Library.

On the Suspended Zenith Telescope of Durham Observatory. Part I. By E. H. Hills, F.R.S. (Plate 6.)

I. History of the Instrument.

In the course of a series of observations with the Durham almucantar in 1912 (v. *M.N.*, 73, 369) it was clearly brought out that the precision obtained with a floating instrument of that type, used away from the zenith, was not likely to approach that of other instruments designed for the same class of work. At the same time the results obtained at Greenwich with the Cookson zenith telescope seemed to indicate that with a floating instrument, used near the zenith, a very high order of accuracy could be secured. It occurred to the author that it would be interesting to try the experiment of a zenith telescope on somewhat similar lines to the Cookson, but with the substitution of a system of suspension for that of flotation. By this device it seemed that all possibility of temperature disturbance in the instrument could be eliminated, as no temperature variation in the suspension system would affect the verticality of the collimation axis. It could also be made an instrument of complete mechanical symmetry, capable of being enclosed in an outer case, and either maintained at constant temperature or, if that were not found expedient, being so insulated that any temperature change would be very slow. In general it appeared that instrumental errors could be reduced to negligibly small magnitudes. A preliminary design was accordingly made and the curators of the Durham University Observatory

authorised the provision of the instrument. The work was put in the hands of Messrs. Cooke of York and detailed drawings were made in the summer of 1913.

While these were in progress it was brought to notice that the late Dr. Schwarzschild, then Director of the Potsdam Observatory, had, while he was in charge of the Observatory of Göttingen, used an instrument of similar type which had only given him partial satisfaction (v. *Abhandlungen der K. G. der Wissenschaften zu Göttingen*, 18, 3, 1911; see also *Ast. Nach.*, 3913 and 3924). The question whether it was advisable to proceed with the Durham instrument therefore required reconsideration. On study of Schwarzschild's memoir it appeared that he had abandoned further observation not on account of any defect in the general theory of a suspended instrument nor of any impossibility of realising with it a very high degree of precision but solely on account of the labour of measuring and reducing the plates. He came to the conclusion that the same order of accuracy could be obtained with a visual instrument in less time. It, however, appeared clear that his methods of reduction were unnecessarily complicated and that the processes were capable of considerable simplification. The advantages, moreover, of a photographic telescope for a small observatory such as Durham, as enabling a single observer to carry on work with two instruments simultaneously, appeared to be very great.

The question was also discussed personally with Dr. Schwarzschild at the Bonn meeting of the International Solar Union in 1913 August, and he strongly urged the value of further trial. Dr. Schlesinger, Director of the Allegheny Observatory, whose experience in photographic observations is second to none, also expressed his strong belief in the future of a photographic telescope on the suspension principle, and he kindly offered the loan of a ten-inch plane parallel glass. This, placed in front of the lens, would enable the whole instrument to be enclosed and thus greatly assist in maintaining it at a nearly constant temperature. This offer was gladly accepted.

The work was accordingly proceeded with and it was hoped to have the instrument mounted in the summer of 1914. The war upset this calculation. The observer in charge went on service and the observatory was closed, except for routine meteorological records, and remained closed until 1919 August. The construction was completed by Messrs. Cooke in 1914 October, and they retained possession until the pier could be built.

This was done early this year, and the mounting was finally achieved in 1920 March.

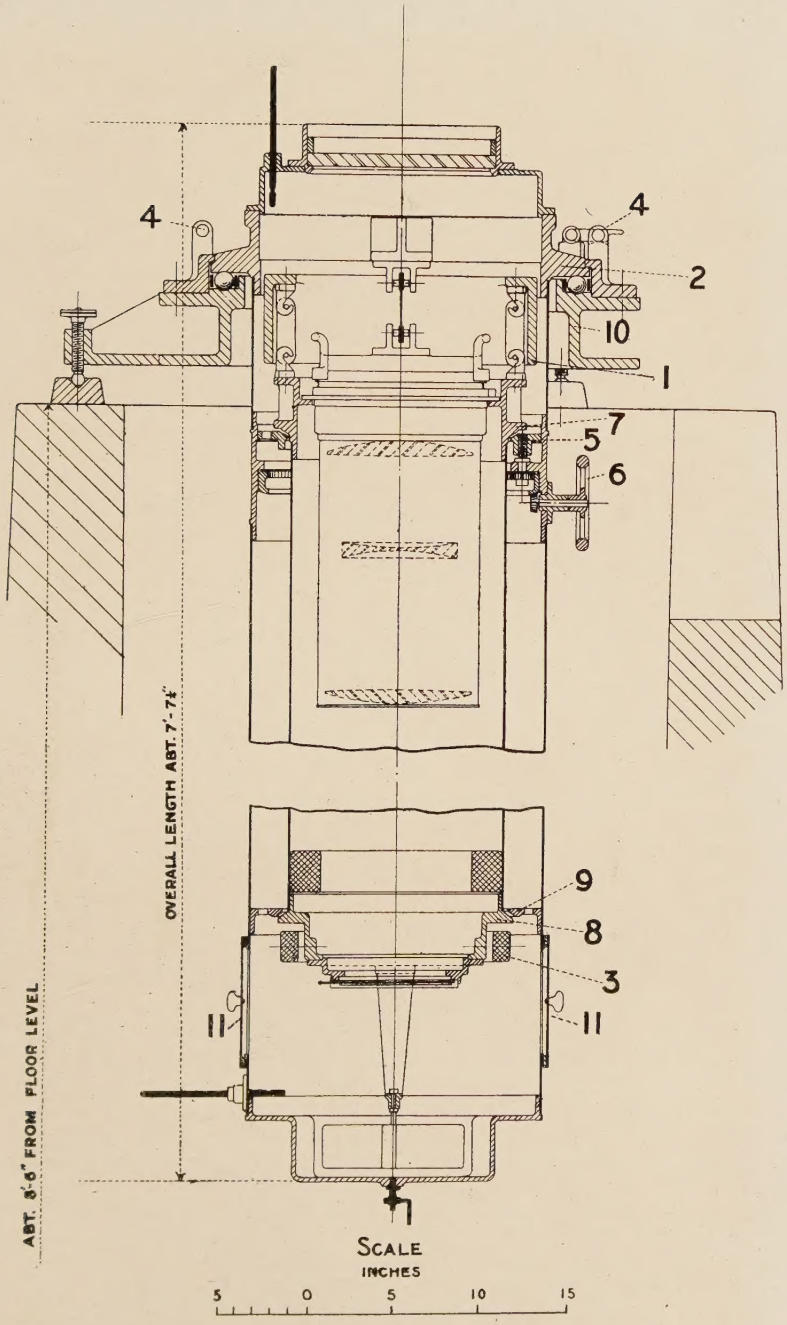
It perhaps need hardly be pointed out that the climate of Durham is most unfavourable for observation and that the chances of securing a whole year's cycle of observation for determination of variation of latitude and constant of aberration are small. There is, moreover, only one observer at Durham, and the labour of obtaining and reducing such a set would be altogether excessive.

It is, therefore, not hoped or expected that Durham can compete with Greenwich or other observatories in the continuous determination of latitude. What can be done is to prove whether or not this form of instrument is an efficient one.

The suspended telescope presents the paramount advantage that the accuracy of the results is not affected by the nature or stability of the mounting; no change in level of the piers, of any order possible, could alter the position of the vertical line through the centre of gravity with respect to the zero point on the plate (v. *infra*, Chap. III.). The instrument is therefore particularly adapted as a portable one, and could be transported to a new place, set up, and plates secured, with only trifling delay for adjustment. The complete solution of all the problems arising out of latitude variation demands observations at a large number of different stations distributed both in latitude and longitude. The zenith camera is well suited for this purpose. Where an observatory is already in existence the addition of a photographic instrument requiring no clockwork or guiding would add little to the work of the observers, and its possible future use, after preliminary testing in its home of origin, will be to spend periods of something over a year at such other observatories as will offer it a temporary home. It may thus accumulate records of latitude change which, when co-ordinated with the continuous records obtained at Greenwich and at the stations of the International Latitude series, should help forward the complete elucidation of this and cognate problems.

II. General Description.

A photographic telescope of 8 inches aperture and 56 inches (1422 mm.) focal length provided with a Cooke astro-photographic lens, series 1 C., is hung by two flat steel pendulum springs from a brass ring **1**, which ring is again in its turn hung by two similar springs, at right angles to the first pair, from the heavy iron carrying ring **2**. The brass ring thus acts as a gimbal, and the whole telescope is in free suspension. When the carrying ring is rotated the telescope will turn about the true vertical passing through the centre of gravity of the hanging part. No alteration in the suspension system affects this verticality until the carrying ring is tilted to such an angle that the elastic resistance of the springs comes into play and the telescope is forced out of the vertical by their reaction. The point at which this arises is calculated below; for the present it will suffice to state that it cannot be reached in practice. The lengthening of one or more of the springs has no effect on the suspension, so that irregular temperature distribution in the instrument would not in any degree alter its position of rest. At the lower end of the telescope a heavy lead ring **3** is attached by four screws, by which its position can be adjusted to bring the vertical line through the centre of gravity to pass through the centre of the plate. The carrying ring runs upon a ball race, and can be completely rotated



DURHAM ZENITH TELESCOPE. MERIDIAN SECTION.

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by hand. It can be clamped in two positions 180° apart by the two adjustable stops 4. We have, therefore, the centre of the plate as the reference point marking the projection of the apparent zenith, and a line across the plate marking the projection of the meridian. When stars are allowed to trail they will cross the meridian at distances from the centre proportional to the tangents of their zenith distances. On rotating through 180° the stars will cross in the reverse direction, and a complete plate will thus show the trails of one or more groups of stars, from the measurement of which the true, corrected position of the zenith will be determined and the latitude of the instrument at the time of exposure fixed.

The telescope is allowed to hang freely only when an exposure is in progress or when necessary to test the adjustments in the working position. At all other times, and specially when the instrument is being rotated or handled, the weight is taken off the springs by the locking ring 5, actuated by the handle 6. This handle rotates three screws which lift the locking ring until it comes into contact with the ring 7, on the hanging part. Further movement then raises the whole telescope until the projecting ring 8 at the bottom comes into contact with the fixed ring 9. The telescope is then locked top and bottom and has been raised far enough to take the weight off the springs but not far enough to allow the pins through them to escape out of the suspension hooks.

To damp vibration and bring the telescope quickly to rest after rotation a four-armed vane, dipping in a glycerine dashpot, is fixed at the lower end. The dashpot has eight fixed vanes or projections round its side to check circular motion of the liquid.

The whole is enclosed in an outer case of sheet iron which is attached to the carrying ring and rotates with it and carries the locking mechanism and the dashpot. The ball race upon which the carrying ring revolves runs upon the fixed ring 10, supported by three levelling screws upon steel plates set in the top of a circular pier of reinforced concrete.

Access to the telescope for insertion and removal of the plate-holder is given by two doors 11 at the lower end of the case. The top is closed in by the ten-inch plane parallel glass so that when the doors are shut the instrument is in an airtight enclosure. Thermometers are provided at top and bottom for reading the temperature of air inside the case. When the design was first made it was intended to add a thermostatic arrangement to keep the internal air at constant temperature during exposure, and to this end two air inlets are provided at the bottom and two similar outlets at the top, while the two locking rings, 5 and 9, are perforated with half-inch holes so that air can freely circulate in the case. On further consideration it has been decided not to attempt this, at all events in the first instance. To maintain such a large mass of metal at a uniform temperature would require a rapid circulation of air, and the risk of displacing the hanging part by a current seems to outweigh any possible advantage to be gained by

the maintenance of a constant temperature. In any case, the temperature change will be slow and the necessary corrections should be easy to apply. The instrument may be said to be doubly insulated. In the first place the iron case can be covered with felt or similar non-conducting material; and secondly, the whole is completely surrounded by the concrete, itself an effective insulator.

To ensure that the photographic plate is always brought into the same position with respect to the optical axis, the base end of the telescope is formed by a circular metal disc attached by three pairs of antagonising screws. At the centre is a rectangular opening, 145 × 70 mm., and three screws close to the sides of this opening project below the surface. The holder containing the photographic plate, which is 160 × 80 mm., is placed in position below, the shutter is entirely drawn out and removed, and the plate is then raised by screws furnished with springs, so that no extreme pressure can be applied, until it rests against the three screws round the opening. It follows that the position of the plate is thus absolutely determined by these three screws, and depends in no degree upon the fitting of the plate-holder. This arrangement is similar to that adopted in the Cookson telescope.

To mark the fiducial lines on the plate two fine silver wires are stretched across the opening, almost but not quite in contact with the sensitive film. These wires will impress their shadows upon the plate and, when all adjustments are correct, the resulting lines will mark the projections of the North-South and East-West lines, and their intersection the projection of the zenith, on the plate. For purpose of adjustment it is necessary to be able to view these cross wires either from below or from above, in which latter case they must be illuminated from below. It has been made an essential point of design that all adjustments shall be carried out with the instrument in exactly the same balance as during exposure. The back of the plate-holder is therefore made of ruby glass, and such adjustments as are made visually can be done with the holder in place and with a sheet of plain glass, of the same size and weight as a sensitive plate, in the exposing position.

The four steel suspension springs are 50 mm. long, 25 mm. broad, and 0·1 mm. thick. The sectional area of one spring is therefore 2·5 mm.^{2}

The weight of the hanging part is 126·46 kgs., and the loading on either pair of springs is therefore:—

$$\frac{126{\cdot}46}{5} = 25{\cdot}3 \text{ kgs. per mm.}^2;$$

a weight well within the limit of safety. Should an accident occur and a spring break, the telescope would fall only the very small distance separating the two upper locking rings 5 and 7.

Damage is therefore impossible.

III. Adjustments and Limits of Error.

The possible instrumental errors may be conveniently divided into three classes:—

A. Errors of adjustment, viz.:—
   (1) *Level.*—Carrying ring out of level, bringing the elastic force of the springs into play.
   (2) *Tilt.*—Plate not normal to optical axis.
   (3) *Eccentricity.*—Foot of normal to plate from optical centre of lens not coincident with intersection of vertical with plate.
   (4) *Orientation.*—Fiducial line not truly North and South.

All these can be reduced to negligible amounts.

B. Instrumental displacements which are always completely negligible, viz.:—
   (5) Magnetic attraction on hanging part.
   (6) Capillary attraction of liquid in dashpot.
   (7) Change of balance owing to plates varying slightly in size.

C. The temperature error.

In the following discussion of the adjustment errors certain assumptions will be made. The scale of the plate is such that $1'' = \cdot0069$ mm., say $0''\cdot01 = \cdot00007$ mm. It is assumed that it is not possible to measure a star trail on a plate with a greater precision than $\cdot0001$ mm., so that, as far as the actual measurements are concerned, the limit of accuracy with which the ZD of a single star can be fixed is $0''\cdot014$. The level error is constant over the plate and independent of ZD, the other adjustment errors change sign for stars on opposite sides of the zenith, and completely disappear if stars are combined in pairs at equal ZD North and South. It will, of course, not be possible to ensure this condition being exactly fulfilled, but it can and will be ensured that any plate accepted for final measurement contains about the same number of stars on each side. For computation of adjustments it is, however, assumed that the latitude is deduced from the trails of one single star measured on both sides of the centre. In order to be completely upon the safe side the further assumption is made that this star is one at the extreme edge of the plate. For simplicity of calculation this is taken as 3° ZD, though it should be noted that the effective size of the plate, being limited by the opening in the base, allows only of a maximum ZD of $72\cdot5$ mm., equivalent to $2^\circ\ 54'$. With these extreme assumptions it would appear that if one-third of the measurement error, as defined above, viz. $0''\cdot005$, is taken as the limiting deviation beyond which it is not necessary to adjust, and the adjustments are calculated upon this basis, the residual errors will be negligible. It will, however, be seen when the calculations are set out that this limit is so easily attainable that it is possible, without undue expenditure of time upon preliminary work, to carry the adjustments to a still finer

point. They can in fact easily be carried to the point where the maximum error of the single star of 3° ZD does not exceed 0″·002. Each adjustment will now be separately computed.

(1) *Level.*—If the carrying ring is tilted in a North-South direction the two suspension springs will be bent. Their elastic resistance will tend to force the hanging telescope out of the vertical.

If α_0 be inclination of ring to the horizontal,
α ,, telescope ,, vertical,
then $\alpha_0 - \alpha$ is the angle between the ends of the bent springs.

The bending moment of a spring of thickness $2a$, width $2b$, and length l, coefficient of elasticity E, for a small angle of bend,

$$= \frac{\mathrm{E}4ba^3(\alpha_0 - \alpha)}{3l}.$$

For the telescope of weight W, length from point of support to centre of gravity L, the turning moment

$$= \mathrm{WL}\alpha.$$

For equilibrium this is balanced by the bending moments of the two springs, and we therefore have—

$$2\frac{\mathrm{E}4ba^3(\alpha_0 - \alpha)}{3l} = \mathrm{WL}\alpha,$$

or,
$$\alpha = \alpha_0 \frac{8\mathrm{E}ba^3}{8\mathrm{E}ba^3 + 3\mathrm{WL}l},$$

which, since $\mathrm{E}ba^3$ is small compared with $\mathrm{WL}l$,

$$= \alpha_0 \frac{8\mathrm{E}ba^3}{3\mathrm{WL}l},$$

substituting values:—$2a = 0{\cdot}1$; $2b = 25$; $l = 50$; $\mathrm{W} = 126{\cdot}46$; $\mathrm{L} = 1504$; E (for steel) = 20,000 kgs. per mm.^{2}

$$\alpha = \frac{\alpha_0}{114{,}000}.$$

A deviation of 114″ in the level of the ring thus corresponds to a displacement of 0″·001 in the position of the apparent zenith.

It would therefore require the ring to be out of level by 10′ before the limiting error of 0″·005 is reached. As, however, it is easy to level the ring quite precisely, it is assumed that it is levelled, say within 1′, in which case the error cannot exceed 0″·0005.

(2) *Tilt.*—This is adjusted either by the three screws against which the plate is pressed when in the exposing position or by the three screws attaching the base plate to the telescope. It can be tested by well-known methods, and there should be no difficulty in adjusting it within 2′.

For the error due to mal-adjustment we have:—C is the centre of the plate. CE the section through the plate in correct adjustment,

i.e. normal to the vertical line OC. Tilt $= \alpha$. OC = focal length $= f$. Then the sections through the plate in direct and reversed positions

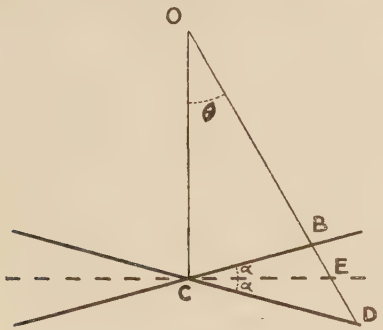


Fig. 1.

will be CB and CD, and the mean of the two measured co-ordinates of a star of $ZD = \theta$ is

$$\frac{CB + CD}{2}.$$

The error due to tilt therefore

$$= \frac{CB + CD}{2} - CE$$

$$= \frac{f}{2}\left\{\frac{\sin\ \theta}{\cos\ (\theta - \alpha)} + \frac{\sin\ \theta}{\cos\ (\theta + \alpha)}\right\} - f \tan\ \theta.$$

For an error of 0″·005 in ZD, equivalent to ·000035 in the measured co-ordinate, we have therefore

$$\frac{\sec\ (\theta - \alpha) + \sec\ (\theta + \alpha)}{2} - \sec\ \theta = \frac{\cdot 000035}{f \sin\ \theta}$$

or, with $f = 1422$, and $\theta = 3^\circ$

$$= \cdot 00000046,$$

giving

$$\alpha = 3'.$$

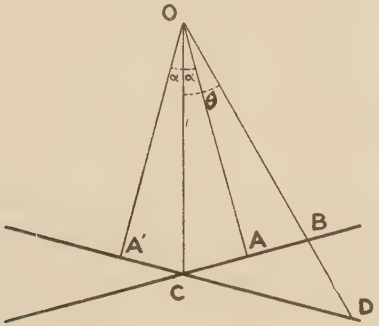


Fig. 2.

(3) *Eccentricity.*—The adjustment of centre of plate to coincide

with the intersection of plate and vertical through the centre of gravity is made by the lead ring at base of telescope. The cross wires are viewed either from above with a telescope or from below with a microscope and the ring moved by its screws until the intersection of the wires remains fixed on rotation. No difficulty should arise in adjusting within 0·5 mm., equivalent to an angular displacement of telescope of 1′ 15″. Any mistake in this adjustment will be quickly seen when star plates are measured.

Using same notation as before: OA = focal length = f.
Error due to mal-adjustment

$$= \frac{AB + A'D}{2} - f \tan \theta$$

$$= f \frac{\tan (\theta + \alpha) + \tan (\theta - \alpha)}{2} - f \tan \theta,$$

which, as before, must not exceed ·000035;

or, $$\frac{\tan (\theta + \alpha) + \tan (\theta - \alpha)}{2} - \tan \theta = \cdot 000000025,$$

giving $$\alpha = 2'30'' \text{ or } 1{\cdot}0 \text{ mm.}$$

(4) *Orientation.*—This is regulated by the adjustable stops which define rotation of carrying ring, and will be best tested by measurement of star trails on an actual plate. It can certainly be tested within 1′. This, however, by itself does not prove that the instrument can, on rotation, be stopped with this precision in practice. To prove this the conditions at the stop must be considered.

The distance from centre line of instrument to stop is 280 mm. At this radius 1′ = ·08 mm., say three-thousandths of an inch. The stops are set in springs, so that the instrument is brought to rest with constant pressure upon the bearing surfaces. The limit of possible deviation is far below the above quantity and could, in no circumstances, exceed one-thousandth of an inch. The maximum deviation of 1′ is thus easily attainable.

FIG. 3.

For the error we have:—CE is true projection of NS line. CB is centre wire along which measurements are made. Error due to deviation α (neglecting curvature of star trail EB, which is quite inappreciable in this small distance),

$$= CB - CE$$

$$= CE(\sec \alpha - 1)$$

Therefore, as before:—

$$\sec \alpha - 1 = \frac{\cdot 000035}{f \tan \theta} = \cdot 00000046,$$

giving $$\alpha = 3'.$$

The adjustment errors may now conveniently be summarised in tabular form, always remembering that the level error is constant over the plate and is independent of the number of stars or their zenith distances, while the tilt, eccentricity, and orientation errors vanish when stars are measured in balanced pairs or groups, and are functions of ZD, vanishing when ZD = 0. These errors, furthermore, will effectively vanish when any mal-adjustment is constant throughout a series of observations, as they will then take the form of a change of apparent scale value. It is therefore important that these adjustments should be made once for all and not disturbed during a series. Level, on the other hand, must be tested at frequent intervals.

Adjustment.	Deviation in adjustment, giving error of 0″·005 in deduced ZD or latitude.	Actual limiting adjustment deviation.	Actual maximum error.
Level	10′	1′	0″·0005
Tilt	3′	2′	0″·002
Eccentricity	1·0 mm.	0·5 mm.	0″·002
Orientation	3′	1′	0″·001

The errors of class B, always completely negligible, can be dismissed with short notice.

(5) *Magnetic Attraction.*—A hanging telescope made of iron would be attracted from the vertical by the horizontal magnetic force. The possible deviation can be readily calculated, but as this danger was realised from the first the design of the Durham instrument includes no iron in the suspended portion except the suspension springs. No magnetic attraction therefore arises.

(6) *Capillarity.*—The vanes on the rod at base are completely submerged in liquid of dashpot. No capillary attraction therefore exists except with the rod where it passes through the surface of the liquid. If the rod is truly central no disturbing force results, but if out of centre the capillarity will pull the telescope away from the vertical and an error of eccentricity will be given.

For the possible amount of this error we have:—

Circumference of rod = 16 mm.; capillary force between glycerine and brass = 7 mgs. per mm. Total force, therefore, = 112 mgs.

As the weight of the telescope is 126·46 kgs., it follows that the eccentricity cannot exceed 1/1,000,000 of the distance of the centre of rod from true centre line.

No measurable eccentricity is thus possible.

(7) *Irregular Size of Plate.*—The addition of a strip at one edge of a plate gives an extra weight acting on a lever arm of

80 mm. For this to produce an eccentricity of ·5 mm. therefore means an added weight of 1/160 of the weight of telescope. The extreme size of plate is limited by the dimensions of the holder and, in any case, no possible addition can amount to more than a minute fraction of this quantity. It is also clear that no practicable variation in the thickness of the plate can produce any appreciable eccentricity, so that no special precautions are required as to the type of glass used.

As all the errors of Class A can thus be rendered negligible, while those of Class B are always inappreciable, there remains only the change of scale due to the action of varying temperature to be considered and allowed for in the reductions. No complete discussion of this is possible until a number of plates have been measured, and until it has been ascertained within what limits temperature can be maintained constant during exposure.

It would obviously lead to great simplification of work in the reductions if the change of focal length could be computed as due directly to the expansion of the telescope under the ordinary law, and consequently if the correction to the measured position of a star trail could be computed as a linear function of the difference of expansion of brass and glass. This would assume, what is probably true within practical limits of error, that the temperature change introduces no distortion into the field. It would be necessary to ensure that the plate is always held during exposure in the same way, *i.e.* either with the centre fixed or with one end fixed so that it will always expand and contract in the same direction. This condition presents no difficulty.

The results obtained with the instrument will form the subject of a further communication.

The Great Sun-spot Group and the Magnetic Storm, 1920 *March* 22–23. By the Rev. A. L. Cortie, S.J. (Plate 7.)

1. *Life-History of the Sun-spot Group.*—The life-history of the great sun-spot group, which crossed the sun's visible disc 1920 March 16–29, presents several points of interest both in itself and in its connection with the exceptionally violent magnetic storm of March 22–23. The first appearance of the group was as a very small spot near the sun's following limb, 1919 December 27. It was accompanied by a few flecks of bright faculæ. Its position was latitude $-5°{\cdot}5$, and longitude 112°. As it crossed the disc, December 27–January 5, it developed into an important bipolar group, in mean latitude $-6°$, and extended from longitude 96° to longitude 113°. The appearance of the group is shown on the accompanying chart. The stream of spots was lying parallel to the sun's equator. Its greatest disc-area during this appearance was 9·0, in units 1/5000 of the visible hemisphere.

At its next appearance, 1920 January 21–February 3, the

group was in the form of a fine long stream of spots, extending from longitude 108° to longitude 133°, and it had just doubled its apparent disc-area. The stream, which at its former appearance had been parallel to the solar equator, was now inclined to it at an angle of about 45°.

At the third return, February 17–26, the group had almost died away, and there remained but one small spot followed by scattered dots. The apparent disc-area had dwindled from 18·0 to 0·6 unit. This small group was surrounded by very extensive faculæ, which covered a very large area of the sun's surface, when the group was dying out near the sun's preceding or W limb, on February 26. The mean position of the principal spot was latitude −6°·0, longitude 131°. It occupied, therefore, a position which was within one degree of the centre of the very great group which appeared at the next rotation.

This revival of the group, March 16–29, was on an immense scale. The group was the greatest seen since the group of 1917 August, and very nearly equalled it in total disc-area. It covered 34 units. Its mean latitude was −6°·0, and it extended in longitude from 114° to 150°. The extreme length of the group was therefore 36°, and the breadth, if a small companion group be included as part of the general disturbance, was 10° in latitude. The centre of the leader spot was in longitude 143°, and that of the following spot in longitude 114°. The intermediate positions were occupied by many smaller nuclei surrounded by extensive penumbræ. It now lay parallel to the sun's equator.

The comparison of the positions of the group in the first and second appearance shows a latitudinal drift in the following portion of the group, and suggests a rotation of this portion of the group in a clockwise direction. If this is indicative of a magnetic field, it would appear that it ought to be such as would show south magnetic polarity. It is not at all unlikely that the strong magnetic fields of sun-spots, and the general magnetic field of the sun, are due to the surface motions as indicated by the flow of the spots and of the faculæ.

2. *The Terrestrial Magnetic Phenomena.*—The months of 1919 December, 1920 January and February, were magnetically quiet months. In 1919 December only two days, the 14th and the 15th, received the international magnetic character 2, which signifies highly disturbed; in 1920 January there was no day deserving that mark; and in February but three days, the 16th, 17th, and 24th.

The successive appearances of the spot-group were accompanied by a moderate movement of the magnets on 1920 January 1 (character 1), and a similar moderate disturbance on January 28. When the original disturbance was dying out there was a considerable magnetic storm (character 2) on February 24. The extreme range in declination, or horizontal direction, was 26′, and in horizontal force 115 γ ($1\gamma \equiv 10^{-5}$ C.G.S. unit).

These disturbances occurred at 27-day intervals. The revival

of the sun-spot group in March was accompanied, March 22–23, again after a 27-day interval, by a magnetic storm of extreme violence. A full description of this storm, as recorded by the Stonyhurst magnetographs, was published in *Nature* for 1920 April 1.

The extreme ranges in the three magnetic elements were very great, in H.F. over 700 γ, as the spot of light went beyond the limits of registration; in V.F. greater than 900 γ, for a similar reason; and in D. the very great range of 2° 40′, which is most unusual. Violent and rapid oscillations were characteristic of this storm, exceeding 300 γ in H.F., and of 90′, 120′, and 130′ in D. Some idea of the great violence of the storm may be obtained by a comparison of these readings with the mean values of H.F. and D. for all days during January and February, which were 40 γ and 9′·5. These violent oscillations were superposed on a general movement of the spots of light in sinuous S-like curves, the values of force, accompanied by a westerly swing of the direction needle, increasing during the daylight hours, and decreasing, accompanied by a reversed movement of the direction needle, during the night hours. The storm commenced by a sudden movement of the needles, at 9^h 6^m approximately, on March 22, and in its more violent phases lasted for about twenty-four hours.

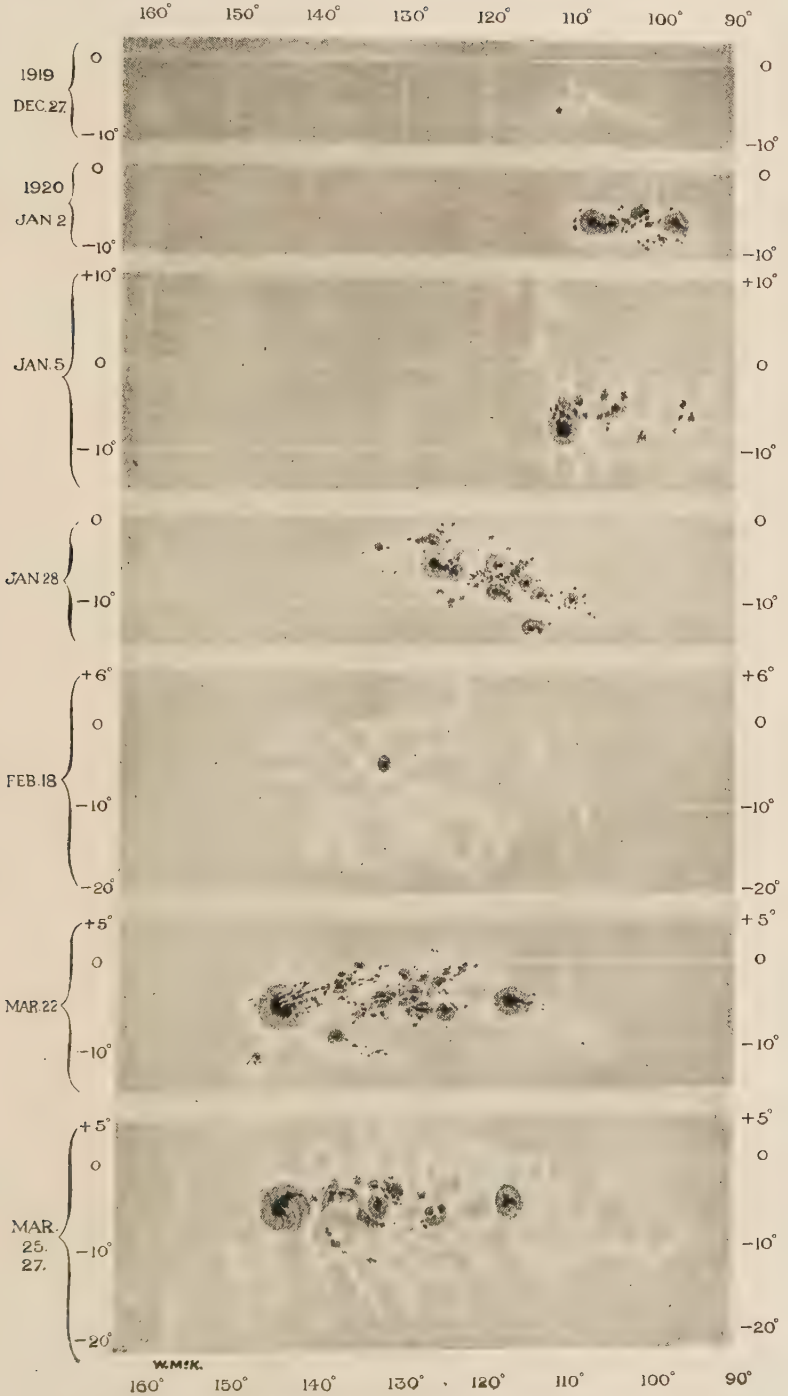
In former papers * evidence has been adduced to show that the greater frequency of magnetic disturbances near the equinoxes is due, not to the position of the sun with regard to the earth's equator, but to the fact that, near the equinoxes, the heliographic latitude of the earth is in the sun's semi-equatorial plane—that is, in the region of the sun-spots.

Again, such heliographic positions of the earth are particularly favourable for the occurrence of magnetic storms, in the period after the maximum of a sun-spot cycle, when the mean latitude of the sun-spots is falling towards the solar equator. From a former study of "The Efficiency of Sun-spots in Relation to Terrestrial Magnetic Disturbances," † it was shown that the "efficiency-ratio" of the numbers expressing the mean yearly number of magnetic disturbances, and the mean daily disc-area of spots, was three times as great in years when the latitudes of the spots were decreasing, after the maximum had been attained, as at the maximum of a spot-cycle.

In the present instance both these conditions obtained. The spot-group appeared near the equinox: it was in low S. latitude. Moreover, other conditions for a great magnetic storm were favourable. The earth's heliographic latitude at the time was only one degree below that of the mean latitude of the spot-group, and the spot-group of enormous size showed great internal disturbance.

But, it may be objected, the conditions of great size and internal disturbance, joined with low latitude and proximity to the heliographic position of the earth, existed at the second

* *Monthly Notices, R.A.S.*, 73, 58, 1912; 76, 17, 1915.
† *Ibid.*, 76, 16, 1915.


160° 150° 140° 130° 120° 110° 100° 90°
1919 DEC. 27
0
−10°
1920 JAN. 2
0
−10°
JAN. 5
+10°
0
−10°
JAN. 28
0
−10°
FEB. 18
+6°
0
−10°
−20°
MAR. 22
+5°
0
−10°
MAR. 25. 27.
+5°
0
−10°
−20°
W.M.H.K.
160° 150° 140° 130° 120° 110° 100° 90°

appearance of the sun-spot, when the accompanying magnetic disturbance was but of moderate intensity (character 1). At the next, the February appearance, when the spot had dwindled to very small dimensions, though it is true the faculæ were most extensive and the earth's heliographic relation to the spot was somewhat better, the magnetic efficiency was increased, the accompanying magnetic disturbance being quite considerable (character 2).

One conclusion, however, derived from a comparative study of sun-spots and terrestrial magnetic phenomena in a review of the greater magnetic storms in the period 1898–1911,* was thus stated: "If we suppose that the ionisation of the upper atmosphere is a condition for a magnetic storm, then it may well be that the process is a gradual one as spots begin to grow in number and magnitude, until the advent of a specially active or large spot suffices to bring about a great magnetic storm." The process may be likened, by analogy, to that of charging up a condenser to a potential difference of discharge. In the present instance there had been a very marked drop in the values of the monthly ranges of the magnetic elements since 1919 October. We may, therefore, reasonably suppose that the ionisation of the upper atmosphere of the earth, due to the successive presentments of the disturbed sun-spot region, was not sufficiently great in December and January to precipitate a very great storm, though there were moderate disturbances. The conditions were better in February, when a highly disturbed condition of the magnets corresponded with the third appearance of the disturbed area on the sun. The climax was reached in March, when all the conditions, of a great disturbed sun-spot region, of a favourable heliographic position of the earth, and of a highly charged condition of the upper atmosphere, were realised.

Any one of these three conditions might of itself be sufficiently pronounced to precipitate a magnetic disturbance. This would account for the disparity not unfrequently observed between the area of a spot and the magnitude of the accompanying magnetic storm, as also the occurrence of magnetic disturbances when no spot was observed. The region on the sun might still be magnetically active, the activity being denoted by the faculæ and the flocculi. Or again the clouds of ions ejected in former rotations might remain undissipated, in which case a relatively small solar disturbance would be sufficient to precipitate a storm.

Sometimes a large spot is observed without the concurrence of a magnetic storm. But a spot can be of large area and at the same time not very active. The active type of sun-spots is type II. of my classification,† identified by Professor Hale as bipolar spots. The large round spot is frequently quiescent.

The due consideration of these three conditions, activity of sun-spot region, favourable position of the earth, and degree of

* *Monthly Notices, R.A.S.*, **73**, 155, 1913.

† *Astrophysical Journal*, **13**, 260, 1901. Cf. *ibid.*, **49**, 20, 1919.

ionisation of the earth's atmosphere, would account satisfactorily for most of the anomalies observed.

The observational data of the present investigation are summarised in the following table:—

Spot-Group.					Magnetic Disturbance.	
Appearance.	Date.	Lat.	Long.	Disc-area.	Date.	Character.
I.	1919 Dec. 27–Jan. 5	−6°	96°–113°	9·0	Jan. 1	1 moderate.
II.	1920 Jan. 21–Feb. 3	−6°	108°–133°	18·0	Jan. 28	,,
III.	,, Feb. 17–Feb. 26	−6°	131°	0·6	Feb. 24	2 very great.
IV.	,, Mar. 16–Mar. 29	−6°	114°–150°	34·0	Mar. 22	2 v. very great

Stonyhurst College Observatory:
1920 *April* 6.

Note on the Secular Accelerations of the Sun and Moon as determined from the Ancient Lunar and Solar Eclipses, Occultations, and Equinox Observations. By J. K. Fotheringham, M.A., D.Litt.

In his paper entitled "The Chief Cause of the Lunar Secular Acceleration," *M.N.*, **80**, 309–317, Dr. Jeffreys uses for the excess of the lunar acceleration over its theoretical value the value $+4''\cdot5 \pm 0''\cdot70$ per century found by Miss Longbottom and myself from the ancient occultations and conjunctions,* and deduces from this a solar acceleration of $+0''\cdot78 \pm 0''\cdot12$ on the theory of tidal friction contained in his paper. He compares the latter with the value $1''\cdot93 \pm 0''\cdot27$ deduced by me from the ancient equinox observations,† and makes the suggestion that either an unknown cause is producing an acceleration of the Sun or that about half the observed solar acceleration is in error.

The observed values used by Dr. Jeffreys are the only values for the lunar acceleration found independently of the solar acceleration, and for the solar acceleration found independently both of the lunar acceleration and of the acceleration of the node of the Moon's orbit, but values obtained from other groups of observations may be used to confirm these or to suggest what errors are possible. I have, therefore, thought it may be worth while to throw the results indicated by different methods together, without waiting for a detailed examination of each group, especially for the benefit of those who may wish to approach the question from another side than that of the ancient observations.

Times of Lunar Eclipses.

The times of lunar eclipses should give us the difference between the lunar and solar accelerations. For reasons given in

* *M.N.*, 75, 393. † *M.N.*, 78, 423.

M.N., **75**, 395, I reject the Babylonian eclipses. I have computed the observed times of the Greek lunar eclipses, and compare them with Dr. Cowell's computed times * in the following table. The correction to acceleration is obtained by multiplying the correction to the time by $-30''\cdot5/T^2$, where $30''\cdot5$ is the difference between the mean motions of Moon and Sun in one minute of time, and T is the interval in Julian centuries since 1800 January 0·0. Where an observation is said to have been made in a particular hour ἀρχομένης or ληγούσης, I have, as in my paper on the ancient occultations, reduced the middle of the first or last third of the hour as the case may be.

Ref. No. and Phase.	Observed G.M.T.	Computed Time.	Correction to Computed Time.	Correction to Acceleration.
	h m	h m	m	″
11 end	6 29·0	6 58·5	−29·5	+2·3
12 beg.	9 27·2	9 41·9	−14·7	+1·1
13 beg.	10 35·7	11 8·3		
13 mid.	12 10·6	12 55·9	−45·3	+3·5
14 beg.	10 57·7	10 52·7	+2·9	−0·2
14 end	13 20·9	13 20·1		
15 beg.	8 16·4	7 40·2	+36·2	−2·9
[15 mid.]	[8 33·5]	[8 22·6]	[+10·9]	[−0·9]
16 mid.	6 26·6	7 9·4	−42·8	+4·7
17 mid.	9 9·2	9 13·9	−4·7	+0·5
18 mid.	8 47·2	9 14·6	−27·4	+3·0
19 mid.	14 13·5	13 54·4	+19·1	−2·1

I ignore the recorded time for the beginning of No. 11, for, since the eclipse began before the Moon rose, the time must have been found by computation, not by observation. I assume that the time given for the middle of No. 13 is the mean between the observed times of the beginning and end, and use this time for purposes of comparison. There is something wrong with No. 15. The eclipse is said to have begun in the beginning of the 5th hour of seasonal time (*i.e.* between $9^h\ 41^m$ and $10^h\ 4^m$ local solar time), which Ptolemy equates with $9^h\ 40^m$ local solar time. The middle of the eclipse is stated—whether from observation or computation is not apparent—to have been $1\frac{5}{6}$ equinoctial hours before midnight, *i.e.* $10^h\ 10^m$ local solar time. Dr. Cowell finds $42^m\cdot4$ as the correct interval between these two phases. Manitius † in his note on the passage computes that according to Ptolemy's theory the interval between the two phases should have been 58 minutes. The probable error of a water-clock five hours after sunset should be about one hour. Perhaps the eclipse is best disregarded. No. 16 is treated by Ptolemy as an observation of the middle of an eclipse. As the observation was made at Alexandria in his own time and

* See *M.N.*, **66**, 524–7.

† *Ptolemäus Handbuch der Astronomie*, **1** (1912), 450.

very possibly by himself, there appears to be no reason to go behind his construction of the observation. Newcomb has rejected this observation, and Dr. Cowell has treated it as an observation of the beginning of an eclipse.

Nos. 11–15 range in date from −200 to −140, Nos. 16–19 from +125 to +136. It seems best, therefore, to treat them as two separate groups. Retaining the first phase of No. 15 and giving equal weight to each observation, we get for the correction to the secular acceleration $+0''\cdot8 \pm 1''\cdot7$. If we reject this eclipse we get $+1''\cdot7 \pm 1''\cdot1$. As the difference between the two results falls within the probable error, it may be best to retain this doubtful phase. The second group gives the mean correction $+1''\cdot5 \pm 2''\cdot0$. In my paper on the "Longitude of the Moon" * I have adopted a mean motion at epoch 1800 exceeding Dr. Cowell's value by $+5''$ and a cube term falling short of his by $+0''\cdot006$. To compensate for these corrections it will be necessary to raise the correction to the acceleration resulting from the first group to $+0''\cdot9$, and that resulting from the second group to $+1''\cdot7$. The mean result from the two groups is then $+1''\cdot1 \pm 1''\cdot3$. Adding this to Dr. Cowell's value for the difference between the lunar and solar accelerations, we get for the difference between the two accelerations resulting from the times of the lunar eclipses:—

$$+6''\cdot8 + 1''\cdot1 \pm 1''\cdot3 = +7''\cdot9 \pm 1''\cdot3.$$

From Newcomb's treatment of these observations with his arbitrarily selected probable errors I obtained in 1915 † the value $+7''\cdot6 \pm 0''\cdot44$.

Magnitudes of Lunar Eclipses.

These are consistent with a value of $+1''$ or $+2''$ for the solar acceleration, giving in neither case an error exceeding half a digit. The mean value of the solar acceleration resulting from these observations is $+1''\cdot78 \pm 0''\cdot45$.‡

Solar Eclipses.

A crucial test for these is the eclipse of Hipparchus. I gave a formula for values satisfying this eclipse in *M.N.*, **69**, 209, accompanied by a not too accurate diagram. The eclipse of Babylon would also appear to be well established. In *M.N.*, **69**, 468, I found that these two eclipses and also that of Archilochus were satisfied by a lunar acceleration of $+10''\cdot1$ combined with a solar acceleration of $+1''\cdot2$. With Dr. Brown's value for the motion of the node,§ these should be reduced to $+9''\cdot9$ and $+1''\cdot0$ respectively. Another very crucial test is the eclipse of Plutarch, if, as seems probable, that eclipse, which had an extremely narrow belt of totality, was total either at Delphi or at Chæronea. Herr Schoch of Heidelberg, who had independently proposed slightly different elements, has recently computed all the principal ancient

* *M.N.*, **80**, 305.
† *M.N.*, **75**, 396.
‡ See *M.N.*, **69**, 666–8; **78**, 422.
§ See *M.N.*, **75**, 510.

solar eclipses, using the expression for the longitude of the Moon given by me in *M.N.*, **80**, 305, Dr. Brown's values for the other elements in the Moon's motion, and Newcomb's solar elements, with unimportant corrections, except that he took the solar acceleration as $+1''\cdot93$. These values seemed to satisfy the whole series of ancient eclipses of the Sun adequately with the exception of those of Pindar, Hipparchus, and Plutarch. The eclipse of Pindar cannot be satisfied without abandoning eclipses more definitely established as total in a particular place. But Herr Schoch found that in order to add the eclipses of Hipparchus and Plutarch to the list of satisfied eclipses without abandoning the others, it was necessary to reduce the adopted solar acceleration by $1''$. This would give $+10''\cdot53$ for the lunar acceleration and $+0''\cdot93$ for the solar acceleration. The latter figure must be raised to $+1''\cdot0$ if Newcomb's centennial motion of the Sun for epoch 1800·0 is to be retained. Herr Schoch does not accept this result, because he considers that a modification of the centennial motion of the Moon is necessary in order to satisfy the eclipse of $+1241$.

Occultations and Conjunctions.

From these Miss Longbottom and I found a lunar acceleration of $+10''\cdot6$ or rather $+10''\cdot8\pm0''\cdot70$.*

Equinox Observations.

On the assumptions that in the earlier series of equinox observations Hipparchus used an approximately fixed equator, and that at the time of his later equinox observations he used the same equator as in his observations of the declinations of stars, the solar acceleration is found to be $+1''\cdot93\pm0''\cdot27$, or $+1''\cdot95$ in excess of the theoretical value.

Comparative Table.

Using L for the lunar acceleration, L′ for the solar, and D for the difference, the following table shows what seem to me the best values obtained hitherto for the different accelerations :—

	Lunar Eclipse Times.	Lunar Eclipse Magnitudes.	Solar Eclipses.	Occultations, etc.	Equinoxes.
L	...	...	$+10''\cdot5$	$+10''\cdot8\pm0''\cdot70$	
L′	...	$+1''\cdot78\pm0''\cdot45$	$+1''\cdot0$	...	$+1''\cdot93\pm0''\cdot27$
D = L − L′	$+7''\cdot9\pm1''\cdot3$	...	$+9''\cdot5$		

The evidence seems to point clearly to $+10''\cdot5$ approximately for the lunar acceleration, and $+1''\cdot0$ or a little more for the solar acceleration.

6 *Blackhall Road, Oxford :*
1920 *April* 8.

* *M.N.*, **75**, 393, 395.

Naked-Eye Observations of Nova Aquilæ III.

By E. E. Barnard.

This star was independently discovered by the writer at Green River, Wyoming, on 1918 June 8, between 10 and 11 p.m., when returning to town from packing the photographic plates at the eclipse station. The discovery was communicated to the Harvard College Observatory telegraphically by Professor Frost. . We know now that the star was discovered earlier on the same date in Europe, in India, and in the southern hemisphere by many observers and by some in this country.

On Sunday, June 9, the nova had very greatly increased in brightness. After it rose that night over a high ridge to the east, it was a most brilliant object. I mentally compared it with Sirius in a similar position, and to me it then appeared as bright as Sirius would have been. It so far outranked all the bright stars then present, such as Altair, Vega, and Arcturus, that any comparison with them was uncertain and difficult. Similar estimations of the light of Sirius made later, after my return to Williams Bay, seem to show that my comparisons on June 9 may have made the nova too bright by something like 0·2 of a magnitude. But I do not like to change the value obtained by me on that night.

When the star was declining in light, I increased the number of comparison stars. On many nights several sets of comparisons were made with many stars. When the nova ceased to be visible to the naked eye it was followed with a field-glass, and with the 4-inch finder of the 40-inch telescope and the 5-inch guiding telescope of the Bruce photographic instrument. The observations made since it ceased to be visible to the naked eye (and the details of the naked-eye observations) are reserved for later publication, for the star is still under observation. I have printed two papers on the peculiarities shown by the nova in the large telescope. They will be found in the *Astrophysical Journal*, 49, 199, 1919, and in *Popular Astronomy*, 27, 450, 1919.

In *Popular Astronomy*, 26, 558, 1918, I have called attention to the improbability that the nova was seen earlier than June 8, as was claimed by quite a number of observers. It was also suggested that one of the supposed observations of the star on June 7 was probably of the star B.D. +0°4027, which is about 20′ north-east of the nova. I am quite convinced that this supposition is correct. I have repeatedly seen this latter star with the naked eye before and since the nova ceased to be so visible, and on several nights the two stars were seen together, so that one would not fail under good conditions to see that there were two stars at this place. This was the case on 1919 April 24 and on May 1, when Mr. Sullivan and I saw both stars with the naked eye.

I have found the nova on my photographs previous to the outburst on fifty-four dates. The earlier of these were with the 6-inch Willard lens of the Lick Observatory, 1892 June 29, 1894 September 20 and 21, and 1895 July 26. The last ones were made

with the 6-inch and 10-inch Bruce lenses of the Yerkes Observatory on 1917 February 19 and March 20. During the period covered by these photographs the light seemed to fluctuate by nearly a magnitude. This is in agreement with the announcement in Harvard College Observatory Circular, No. 658, that in the pre-nova state the star varied in brightness.

The following table contains all my naked-eye observations of the brightness of the nova. The magnitudes are on the Harvard scale. The observations since the star ceased to be visible to the naked eye will be printed later.

Magnitude Observations of Nova Aquilæ III.

1918.	C.S.T.*	Mag.	No. of Stars Used.	1918.	C.S.T.*	Mag.	No. of Stars Used.
	h m				h m		
June 8	11 30	0·4	1	June 28	13 50	3·8	9
	13 15	0·6	4		14 40	3·9	1
9	11 40	−1·3	1	30	9 30	3·7	8
	13 40	−1·4	2		10 30	3·7	3
	16 10	−1·5	2		11 20	3·6	8
10	11 20	0·1	4	July 1	9 35	3·2	7
	13 25	0·3	4		11 40	3·2	11
	14 40	0·5	3		12 30	3·2	8
11	12 30	0·3	1		13 20	3·1	8
12	10 40	0·8	4	2	9 25	3·3	12
13	13 40	1·6	2		12 35	3·3	10
14	9 45	1·8	6	3	12 0	2·9	8
	11 40	1·9	6	5	9 10	3·4	11
15	14 0	1·9	4		11 35	3·3	10
16	11 0	2·1	6		12 40	3·4	11
17	11 0	2·2	4	7	10 30	3·5	5
18	10 20	2·4	9	8	9 20	3·6	14
20	9 5	2·5	3		12 0	3·7	13
	12 40	2·7	10	9	9 50	3·8	15
22	8 45	3·0	8		12 15	3·7	13
	13 45	2·9	18	10	9 50	4·0	12
23	15 0	3·2	5	11	9 55	4·0	13
25	8 45	3·3	5		12 50	4·1	13
	11 50	3·2	6	12	9 10	4·2	9
26	9 25	3·6	6		12 20	4·1	11
	11 30	3·9	2	13	11 50	3·8	17
28	9 15	3·6	2	16	9 15	3·7	8
	10 30	3·7	2		14 10	3·7	8

* C.S.T. = 6h slow of Greenwich mean time.

Magnitude Observations of Nova Aquilæ III.—continued.

1918.	C.S.T.* h m	Mag.	No. of Stars Used.
July 17	11 40	3·6	7
18	11 30	4·0	10
	13 10	3·9	6
	14 10	3·7	7
20	14 20	4·2	9
21	10 35	<3·9	Not seen. Moonlight.
24	8 40	4·1	9
25	8 50	4·0	11
	9 25	4·0	8
26	9 0	3·9	13
27	8 50	3·9	14
29	8 45	4·1	11
	10 15	4·1	14
30	9 15	4·1	12
	11 5	4·1	12
	12 10	4·2	11
31	8 50	4·2	10
	11 45	4·2	13
Aug. 1	8 50	4·6	11
	9 55	4·7	6
2	8 50	4·6	10
3	8 50	4·6	12
	9 30	4·6	9
4	8 50	4·6	20
	13 15	4·5	6
5	8 45	4·7	13
	10 35	4·7	9
6	9 15	4·0	14
7	8 30	3·9	5
	9 30	3·8	5
	11 35	4·0	16
8	8 35	4·1	16
9	11 10	4·0	8
10	8 25	4·2	20
12	8 30	4·5	22
	10 0	4·5	20
	12 15	4·5	8

1918.	C.S.T.* h m	Mag.	No. of Stars Used.
Aug. 14	8 10	4·6	8
15	9 20	4·8	5
24	7 45	4·6	16
	8 30	4·6	14
25	8 5	4·7	16
	8 55	4·7	17
26	8 0	4·4	23
	9 50	4·4	14
27	8 20	4·4	11
28	8 0	4·5	18
	10 30	4·5	14
29	8 20	4·5	11
31	8 0	5·0	20
	10 0	4·9	15
	11 45	5·0	9
Sept. 2	8 40	4·9	19
	10 50	5·0	10
4	9 20	4·7	24
	10 50	4·6	10
5	7 45	4·6	23
	8 55	4·5	19
6	11 0	4·3	13
7	9 0	4·7	20
8	7 45	4·9	21
	9 20	4·8	15
11	8 20	4·7	17
12	10 50	5·0	11
13	7 30	4·8	5
	11 30	5·1	8
16	7 25	5·0	3
21	7 25	4·8	6
22	7 20	4·9	7
23	7 0	4·8	2
	7 30	4·8	13
25	7 0	5·0	15
	9 5	5·1	14
26	7 10	5·0	18

* C.S.T. = 6^h slow of Greenwich mean time.

Magnitude Observations of Nova Aquilæ III.—continued.

1918.	C.S.T.*	Mag.	No. of Stars Used.	1918.	C.S.T.*	Mag.	No. of Stars Used.
	h m				h m		
Sept. 27	8 0	4·9	12	Oct. 9	8 0	5·2	8
28	7 5	5·0	19	18	6 40	5·4	1
	7 30	5·0	18	20	6 10	5·1	4†
29	7 20	5·0	13	21	6 30	5·1	15
30	7 0	5·2	20	27	6 40	5·3	9
Oct. 2	6 50	5·0	20	28	6 55	5·4	7
	8 10	5·0	19	29	7 45	5·5	5
	9 45	5·2	7	Nov. 1	6 25	5·4	15
3	7 10	5·0	19	4	6 15	5·5	13
5	7 50	5·1	14	5	5 30	5·7	1‡
6	7 0	5·1	19		6 50	5·6	6
	7 35	5·0	17	6	6 15	5·4	1†
7	6 50	5·1	17		6 20	5·5	2
9	6 50	5·2	15				

One of the stars used in the observations needs special notice. It is θ Serpentis, which is a well-known double. It was used on a number of nights in the naked-eye observations of the nova. In Harvard College Observatory Bulletin, No. 661, the naked-eye or combined brightness of this star is given as 4·1 magnitude. The Harvard and Potsdam revised values for the individual magnitudes of the components are:—

Harvard.		Potsdam.	
Preceding star	4·50	Preceding star	4·72
Following star	5·37	Following star	5·13
Difference	0·87	Difference	0·41

These are discordant. There is a note to the Harvard values: "The difference in magnitude derived from ten observations with double-image photometer" (*H.C.O. Annals*, **50**, 220). Both results make the difference of magnitude larger that it really is at present. Especially is this the case with the Harvard values. They both give the combined or naked-eye value of 4·1 magnitude, which is that used on the Harvard map. In *Uran. Argent.*, p. 219, Dr. Gould gives the following magnitudes for the components:—

Preceding star $4^{m}\cdot5$ } $4^{m}\cdot2$ Var?
Following star $4^{m}\cdot7$ }

the combined light being $4^{m}\cdot2$. Apparently Dr. Gould thought the star was variable. My observations, extending over several months in 1918–1919, do not show any decided change in either component.

* C.S.T. = 6h slow of Greenwich mean time.
† With Zeiss field-glass.
‡ With 4-inch finder of the 40-inch telescope.

From some thirty nights' comparisons of this star with the nova and many other stars, I make the naked-eye brightness 4·3 magnitude on the Harvard scale. From many comparisons of the relative brightness of the components with 4-inch, 5-inch, and 40-inch telescopes, the following star appears to be the fainter by 0·2 or 0·3 magnitude. This is close to the values given by double-star observers in general. Sometimes there seemed to be scarcely any difference in their light. The Harvard difference at the present time is certainly too large.

While examining the star, which is *Burnham General Catalogue,* No. 8914, on several dates I measured the components:

1919·744 P.A. 103°·9 Dist. 2ʺ·19 (3 n.).

Hough's measures are:

1902·48 P.A. 104°·3 Dist. 2ʺ·18 (3 n.).

The two stars seem to be relatively fixed.

In the star's decline there were a number of rapid increases of light. This was specially marked about July 3, 17, 27, August 7, 26, and September 6. After this the changes were not so abrupt nor so large, but it still seemed to fluctuate in its light and the decline became very slow. It could not be successfully followed with the naked eye after the first part of 1918 November, because of its proximity to the horizon. In November and December of 1918 the nova assumed a beautiful clear-cut planetary disc which could be measured quite accurately and was over a second of arc in diameter (see *Astrophysical Journal*, 49, 199, 1919). In the spring of 1919 the star was a beautiful bluish-green, unmatched for colour by any star in the sky (*Popular Astronomy*, 27, 450, 1919).

Yerkes Observatory,
Williams Bay, Wisconsin:
1920 *February* 25.

Orbit of OΣ 185. By J. Jackson, M.A., B.Sc.

(*Communicated by the Astronomer Royal.*)

This star is No. 4355 in Burnham's General Catalogue and is B.D., +1°, 1959. The position for 1925·0 is $7^h\ 53^m\ 26^s + 1°\ 20'$. The magnitudes are 6·8, 7·0 and the spectrum F8. Porter gives the proper motion as 0ʺ·178 in 269°·0.

It seems now to be possible to interpret the observations of this binary, of which the following is a short history.

It was measured by both Otto Struve and Maedler between 1843 and 1850. The separation was under 0ʺ·5 and for a mean epoch of 1845·27 the position angle was 23°·6. Secchi in 1855 gave the position angle as 265°·0, with the note "apparently separated." In 1861 Otto Struve suspected an elongation in 198°

and in 1869 an elongation in 240°. But in 1870, 1873, it appeared to him to be single. It had also appeared single to Dembowski in 1866, but he had only a 7-inch telescope. Schiaparelli failed to separate it in 1877, 1879, 1882, 1883, and on 5 nights in 1887,

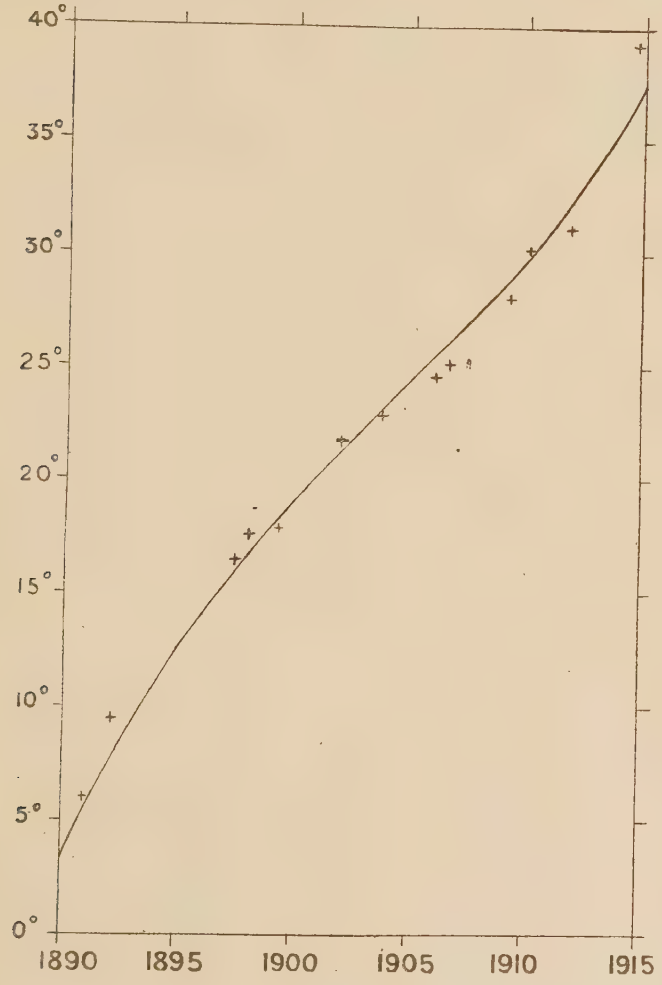


FIG. 1.

although he used the 18-inch telescope at Milan in the latter year. Engelmann, with only a 7-inch telescope, gives measures made on 5 nights in 1883. Reliable observations commenced with Burnham in 1890, and since that time have been very consistent. When the position angles are plotted against the time the points lie very

close to a smooth curve from which the following positions have been read off—

1891·0	6°·0
1896·5	15·3
1902·0	21·3
1907·5	26·3
1913·0	33·6

It thus seems clear that there is a fairly rapid direct motion. The angular motion was a minimum about 1905, indicating a maximum separation at that time. The maximum separation does not exceed 0″·4.

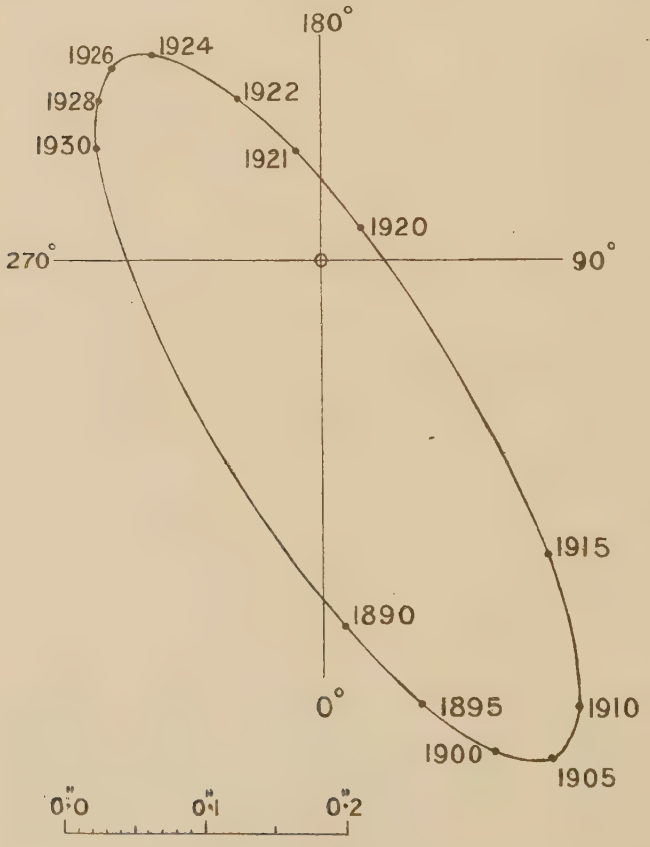


Fig. 2.

Now the position angle corresponding to the maximum separation of 1905 agrees almost exactly with the position angle observed by Otto Struve and Maedler. The only difficulty in the interpretation of the observations is due to the approximate equality of

the two components. It is just possible, though very unlikely, that only 180° of the orbit have been described in the 60 years to 1905. The orbit given below is based on the assumption that the period is nearly 60 years and that the elongations suspected by Otto Struve in 1861 and 1869 are substantially correct. The observation by Secchi in 1855 has been rejected, as also the observation by Engelmann in 1883. A single queried observation by Schiaparelli in 1887 is satisfied to 20°, if the position angle is altered by 180°.

It must be admitted that the orbit given below may be considerably in error, as a result of all the reliable observations lying within 30° of position angle. It is probable, however, that the period is near that given, and the inclination must be large. An orbit could be obtained giving a better fit with the observations utilised, but this has appeared to be unnecessary on account of the uncertainties in the observations. For example, the period could be increased by half a year, when a better fit would be obtained with the observations of 1861, 1869, without altering the ephemeris at the other dates for which there are observations by more than a fraction of a degree. Observations made at the present time with a powerful refractor will be very useful, as the companion is now in a part of the orbit for which there are no observations. If the hypotheses on which the present orbit has been computed are correct, observations during the next 10 years will serve for the determination of an accurate orbit.

The elements have been obtained by Zwiers' method, and the notation used is that of *M.N.*, **80**, 543.

T 1861·16	a 0″·350	i 74°·6
P 59·6 years	e 0·611	Ω 35°·2
n +6°·04		ω 114°·9

The ephemeris is—

1890·0	3°·4	0″·261
1895·0	12·5	0·323
1900·0	19·0	0·369
1905·0	24·3	0·388
1910·0	29·7	0·364
1915·0	37·4	0·264
1920·0	131·1	0·037
1921·0	192·7	0·080
1922·0	207·1	0·131
1923·0	214·1	0·169
1924·0	218·9	0·191
1925·0	222·9	0·202
1926·0	226·6	0·205
1927·0	230·4	0·203
1928·0	234·2	0·197
1929·0	238·4	0·189
1930·0	243·0	0·180

The following is a comparison of the orbit with the observations:—

	Obs.	Comp.	O−C.	Obs.	Comp.	O−C.	
	°	°	°	″	″	″	
1843·26	25·0	22·2	+ 2·8	0·45	0·38	+·07	Ma 2
1844·28	20·2	23·2	− 3·0	0·32±	0·39	−·07	OΣ 2, 1
1850·28	24·1	29·6	− 5·5	0·42±	0·36	+·06	OΣ 1
1855·29	265·0	...	...	App. sep.	0·27	...	Se 1
1861·25	198	188·1	+10	Elong. susp.	0·07	...	OΣ 1
1869·24	240	237·9	+ 2	Elong. susp.	0·19	...	OΣ 1
1883·85	28·4	342·5	...	0·28	0·18	...	En 5
1887·16	337	355·7	−19	?	0·22	...	Schiap. 1
1890·96	6·0	5·5	+ 0·5	0·22	0·27	−·05	β 3
1892·18	9·4	7·8	+ 1·6	0·25	0·29	−·04	β 3
1897·58	16·4	16·0	+ 0·4	0·34	0·35	−·01	Gr. Obs. 5
1898·10	17·6	16·9	+ 0·7	0·53	0·35	+·18	Hu. 3
1898·18	22·3	17·0	+ 5·3	0·29	0·36	−·07	Brown 1
1899·31	17·8	18·2	− 0·4	0·35	0·36	−·01	Brown 2
1902·01	21·7	21·3	+ 0·4	0·34	0·38	−·04	Gr. Obs. 5
1903·82	22·8	23·2	− 0·4	0·42	0·39	+·03	Bies. 3
1906·15	24·5	25·5	− 1·0	0·34	0·39	−·05	A 1
1906·64	25·2	26·0	− 0·8	0·46	0·38	+·08	Doo. 4
1909·29	28·0	28·9	− 0·9	0·32	0·37	−·05	A 1
1910·14	30·2	29·9	+ 0·3	0·38	0·36	+·02	Gr. Obs. 3
1911·91	31·1	32·0	− 0·9	0·39	0·34	+·05	Gr. Obs. 3
1914·60	39·3	36·4	+ 2·9	0·33	0·28	+·05	Gr. Obs. 3

Between 1860 and 1885 the separation did not reach 0″·25, and this gives a complete explanation of the negative observations of that period. In the first diagram the smooth curve shows the ephemeris positions, and the crosses the observed positions since 1890. The diagram of the apparent ellipse shows the computed positions.

If we assume a mass twice that of the sun, the hypothetical parallax is ″·0182.

On Capture Orbits. By Professor L. Becker, Ph.D.

1. The orbits treated in this paper are calculated by mechanical quadrature of the differential equations belonging to the motion of three bodies in a plane.

Let two of the bodies, A and B, form a binary system and the third body, C, approach the system. In certain cases C will be captured by the system and B will leave it. Thus there will again be a binary system in which C has taken the place of the former companion, B, while B is moving away from it.

In the cases treated here I have assumed three equal masses and I have further limited the investigation to certain types of symmetrical orbits.

2. *Symmetrical Orbits of Bodies of Equal Masses.*—C is required to move after capture in an orbit which is an exact reproduction of the orbit of B before capture, but lies on the opposite side of a line of symmetry. Such orbits will occur, as I shall show, under the following conditions:—

Let at zero-time the three bodies have the positions shown in the diagram, A being equally far from B and C. Supposing the velocities to be relative to the centroid G of B and C, let the velocities of B and C be at right angles to the line joining these two positions and the velocity of A be parallel to this line.

Then the C-orbit at negative time and the B-orbit at positive time are symmetrically placed with reference to the X-axis, GA, and *vice versâ*. Further, at the same moment the two bodies stand opposite to one another with reference to their centroid. The A-orbit being also symmetrical with reference to the X-axis, the B-orbit relatively to A at positive time is symmetrical to the C-orbit at negative time.

Hence the calculation of symmetrical orbits has to be made

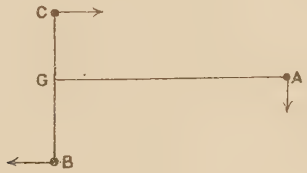


FIG. 1.

only for positive time and thus involves only half the labour required for other orbits.

3. *Capture Orbits.*—The character of the orbits depends on the chosen velocities at zero-time. Capture will occur in the event that one of the bodies, B or C, obtains elliptical velocity with reference to A, while the third body moves away in a hyperbola relatively to the centroid of the two others. The problem can only be solved by trial. Almost all the orbits I calculated turned out to have large eccentricities, and a slight change in the chosen velocities would convert the ellipse into a hyperbola. On the other hand, I have endeavoured to let the third body escape at a hyperbolic velocity only slightly exceeding the parabolic one. In consequence, most of the orbits I calculated finally proved to be failures, the result being generally either two ellipses or two hyperbolas. On an average four attempts were required.

At a given position of the three bodies at zero-time there are four types of orbits. In the first two types (marked I. and II.) the velocity of A is directed downwards as in the above diagram, in the last two types (marked III. and IV.) the velocity of A is directed upwards. After zero-time the binary system consists of bodies A and C for types I. and IV. and of bodies A and B for types II. and III. I calculated two examples of both types I. and III. Type

V., which is represented by one orbit, is characterised by "A" being in the centroid of the other two bodies at zero-time.

I have so far not been able to find capture orbits where A is stationary in the X-axis at zero-time, though undoubtedly they exist.

The following table contains the values of the initial constants. The positions are given in Jacobian co-ordinates, x, y being the co-ordinates of C referred to B and x', y' the co-ordinates of A referred to the centroid of B and C. The directions of the axes are the same as defined in the figure above.

Designation of Orbit.	y	x'	$\frac{dx}{dt}$	$\frac{dy'}{dt}$	Bodies forming Binary System after Zero-Time.
I. 1	+1·5	+3	+2·2	−0·5	A, C
I. 2	+0·3	+3	+4	−1·5	A, C
II.	+1·5	+3	+2·0	−1·0	A, B
III. 1	+1·5	+3	+1·9	+0·9	A, B
III. 2	+1·5	+3	+2·0	+1·0	A, B
IV.	+1·5	+3	+2·3	+0·3	A, C
V.	+0·3	+0	+7	+2	A, C

4. *The Formulæ.*—Let ξ_a, η_a designate the co-ordinates of a body of mass m_a relative to the centroid of the three bodies; x_{ab}, y_{ab} are the co-ordinates of m_a relative to m_b; and r_{ab} is the distance of these two masses. The time unit is so chosen that the constant of attraction equals unity. Then

$$x_{21} = \xi_2 - \xi_1, \text{ etc.}$$
$$F_{21} = m_1 m_2 x_{21}/r^3_{21}, \text{ etc.} \quad (6 \text{ quantities.})$$
$$m_1\ddot{\xi}_1 = F_{21} - F_{13} = N_1, \text{ etc.} \quad (4 \text{ independent equations.})$$
$$m_1\xi_1 + m_2\xi_2 + m_3\xi_3 = 0, \text{ etc.} \quad (2 \text{ equations.})$$

Assume $m_1 = m_2 = m_3 = 1$.

The calculation is made at regular intervals ω in t. The co-ordinates ξ, η being known at time $t = \omega\tau$, the quantities $M_1 = \omega^2 N_1/m_1$, etc., can be calculated for that time. When we consider ξ as a function of τ, say $f(\tau)$, the second difference $f^{ii}(\tau)$ of ξ is found from M and its successive differences, $M^{(n)}$, by the formula

$$f^{ii}(\tau) = M(\tau) + \tfrac{1}{12}M^{ii}(\tau) - \tfrac{1}{240}M^{iv}(\tau) + \ldots$$

and the first difference below the zero-time line, $f^{i}(+\frac{1}{2})$, is calculated from

$$f^{i}(+\tfrac{1}{2}) = \omega\dot{\xi} + \tfrac{1}{3}f^{ii}(0) + \tfrac{1}{6}f^{ii}(1) - \tfrac{1}{12}f^{iv}(0) \ldots$$

Since F_{ab} becomes large when the two bodies a and b approach each other, I calculate *either* M_a *or* M_b and the M belonging to the third body, with the effect that only two of the four co-ordinates for which the integration is effected show large differences at close approaches. This procedure reduces the work considerably.

When the calculation has so far advanced that the distance of the departing body from the other two bodies is a multiple of their mutual distance I calculate the major axis of the conic sections in which the bodies approximately move from the velocities and

distances. The result decides whether a capture orbit has been obtained.

5. *The Numerical Results.*—The tables contain the co-ordinates x, y of C referred to B and the co-ordinates x', y' of A referred to the centroid of B and C. Below each table three elements each of the two orbits are given, viz. the longitude of periastron, semi-major-axis, and the eccentricity. The ellipse is referred to A as focus and the hyperbola to the centroid of the binary system.

6. *The Plates.*—Each orbit is shewn twice. In the first figure the orbits are represented relative to A, whose position is indicated by a ring; in the second figure the orbits are drawn relative to the centroid of B and C and for positive time only. The two figures are drawn on different scales.

ORBIT I. 1.

Time.	x 10^3.	y 10^3.	x' 10^3.	y' 10^3.	Time.	x 10^3.	y 10^3.	x' 10^3.	y' 10^3.
0·00	0	+1500	+3000	0	+ 9	+8011	−7004	+7116	+1181
+0·25	+548	1472	2990	−125	10	8398	7720	7784	1052
0·50	1080	1392	2961	247	11	8782	8404	8419	893
0·75	1592	1276	2912	366	12	9166	9066	9024	708
1·00	2087	1136	2840	478	13	9551	9682	9600	500
1·25	2571	978	2743	579	14	9936	10286	10151	+ 273
1·50	3051	803	2617	662	16	10713	11432	11182	− 231
1·75	3534	606	2457	716	18	11500	12505	12126	794
2·00	4027	370	2258	716	20	12302	13518	12989	1407
2·25	4523	+ 64	2033	607	22	13121	14476	13778	2063
2·50	4956	−358	1884	−326	24	13960	15384	14493	2758
2·75	5239	820	1942	+ 18	26	14822	16250	15137	3490
3·00	5423	1238	2123	297	28	15709	17075	15708	4256
3·25	5579	1610	2352	509	30	16625	17862	16207	5053
3·50	5713	1950	2592	675	32	17574	18614	16629	5881
3·75	5838	2266	2835	807	34	18561	19334	16970	6738
4·00	5957	2563	3076	914	36	19593	20022	17223	7624
4·25	6072	2846	3314	1002	38	20676	20680	17377	8536
4·50	6184	3118	3548	1074	40	21824	21312	17415	9474
4·75	6294	3380	3777	1134	42	23054	21918	17313	10433
5	6402	3634	4002	1183	44	24395	22507	17026	11404
6	6821	4580	4861	1295	46	25906	23091	16472	12373
7	7225	5444	5660	1315	+48	+27719	−23740	+15446	−13232
8	+7621	−6248	+6410	+1272					

$t = +40$

	C.	B.
ω	32°·0	288°·6
a	4·91	−13·2
e	0·837	1·089

ORBIT I. 2.

Time.	x 10².	y 10².	x' 10².	y' 10².	Time.	x 10².	y 10².	x' 10².	y' 10².
0·00	0	+ 30	+ 300	0	+31·44	+2804	−5544	+1203	−1330
+0·24	+ 75	− 1	299	− 35	35·76	3104	6240	1402	1562
0·72	170	77	291	107	40·08	3402	6928	1603	1806
1·20	252	148	274	174	44·40	3699	7608	1803	2058
1·68	335	221	247	235	57·36	4588	9609	2404	3365
2·16	419	300	211	281	70·32	5477	11560	2999	3737
2·64	502	390	175	308	83·28	6369	13469	3585	4667
3·12	577	488	147	320	96·24	7267	15338	4161	5650
3·60	644	591	131	324	109·20	8174	17168	4720	6690
4·08	704	694	124	326	122·16	9095	18957	5260	7788
4·56	758	796	122	328	135·12	10034	20698	5769	8956
5·04	810	896	125	331	148·08	11007	22378	6227	10215
5·52	858	996	132	335	154·56	11516	23185	6421	10892
6·00	905	1093	141	340	156·18	11648	23382	6463	11068
6·48	950	1190	152	346	157·80	11782	23577	6502	11248
6·96	993	1285	165	354	159·42	11919	23769	6536	11432
8·40	1117	1565	208	381	161·04	12060	23958	6564	11620
9·84	1236	1838	258	416	162·66	12206	24144	6585	11814
11·28	1350	2106	313	456	164·28	12360	24325	6593	12013
12·72	1461	2368	370	501	165·90	12527	24502	6581	12220
14·16	1570	2626	430	550	166·71	12620	24590	6562	12325
15·60	1678	2881	490	602	167·52	12723	24679	6527	12427
17·04	1783	3133	552	658	168·33	12841	24778	6470	12515
18·48	1888	3382	615	716	169·14	12969	24908	6398	12555
22·80	2198	4117	808	904	+169·95	+13077	−25065	+6355	−12555
+27·12	+2503	−4837	+1004	−1111					

$t = +28$

	C.	B.
ω	78°·1	232°·0
a	11·12	−1·13
e	0·889	2·357

ORBIT. II.

Time.	x 10^3.	y 10^3.	x' 10^3.	y' 10^3.	Time.	x 10^3.	y 10^3.	x' 10^3.	y' 10^3.
0·00	0	+1500	+3000	0	+18	+14120	−16862	+269	+ 216
+0·25	+ 497	1472	2990	−250	22	15410	20400	326	926
0·50	980	1390	2962	497	26	16552	23740	354	1644
0·75	1442	1270	2914	739	30	17580	26924	346	2380
1·00	1880	1123	2848	974	34	18516	29980	299	3140
1·25	2301	956	2763	1198	38	19378	32922	+213	3928
1·50	2706	774	2660	1408	46	20918	38528	− 72	5599
1·75	3102	578	2541	1602	54	22260	43820	503	7409
2·00	3487	+ 366	2408	1776	62	23434	48844	1074	9369
2·5	4232	− 94	2110	2055	70	24462	53628	1782	11491
3	4938	612	1798	2236	78	25359	58189	2628	13790
3·5	5596	1176	1501	2325	86	26124	62530	3616	16285
4	6202	1776	1239	2342	94	26764	66650	4755	19004
5	7258	3020	839	2247	102	27268	70526	6062	21990
6	8146	4266	578	2072	110	27620	74126	7566	25313
7	8912	5486	412	1871	118	27788	77364	9322	29106
8	9586	6668	309	1665	120	27794	78098	9812	30160
9	10192	7812	247	1461	122	27780	78790	10328	31270
10	10748	8922	212	1261	124	27746	79434	10875	32449
12	11738	11050	192	875	126	27688	80016	11459	33719
14	12610	13070	207	503	128	27596	80512	12090	35113
+16	+13398	−15004	+236	−141	+130	+27462	−80874	−12785	+36706

$t = +130$

	B.	C.
ω	304°·1	64°·2
a	9·23	−12·8
e	0·984	1·275

ORBIT III. 1.

Time.	x 10^3.	y 10^3.	x' 10^3.	y' 10^3.	Time.	x 10^3.	y 10^3.	x' 10^3.	y' 10^3.
0	0	+1500	+3000	0	5	+7494	− 8	− 261	+1236
0·5	+ 940	1386	2961	+ 449	5·5	7994	56	642	1045
1	1810	1120	2833	893	6	8458	104	1036	841
1·5	2640	796	2587	1307	6·5	8882	156	1451	627
2	3470	508	2205	1622	7	9268	214	1896	404
2·5	4284	316	1749	1767	7·5	9608	274	2382	+175
3	5040	202	1302	1771	8	9894	334	2925	− 55
3·5	5734	132	886	1692	8·5	10112	386	3554	274
4	6368	80	494	1566	9	+10220	−400	4327	438
4·5	+6952	+ 34	+ 115	+1411	9·5	...	...	−5357	−366

$t = +8·5$

	B.	C.
ω	34°·9	205°·2
a	2·27	−11·1
e	0·806	1·031

ORBIT III. 2.

Time.	x 10^3.	y 10^3.	x' 10^3.	y' 10^3.	Time.	x 10^3.	y 10^3.	x' 10^3.	y' 10^3.
0	0	+1500	+3000	0	4·5	+7672	+ 26	+250	+2095
0·5	+988	1388	2961	+499	5	8344	− 40	−115	2043
1	1914	1128	2833	992	5·5	8988	106	482	1976
1·5	2818	824	2589	1450	6	9606	176	854	1896
2	3724	560	2219	1802	7	10772	324	1626	1701
2·5	4608	380	1799	2007	8	11844	490	2455	1464
3	5442	260	1387	2103	9	12820	674	3370	1186
3·5	6228	168	995	2135	10	13670	886	4420	865
4	+6968	+ 94	+618	+2128	11	+14336	−1124	−5715	+ 500

$t=10$

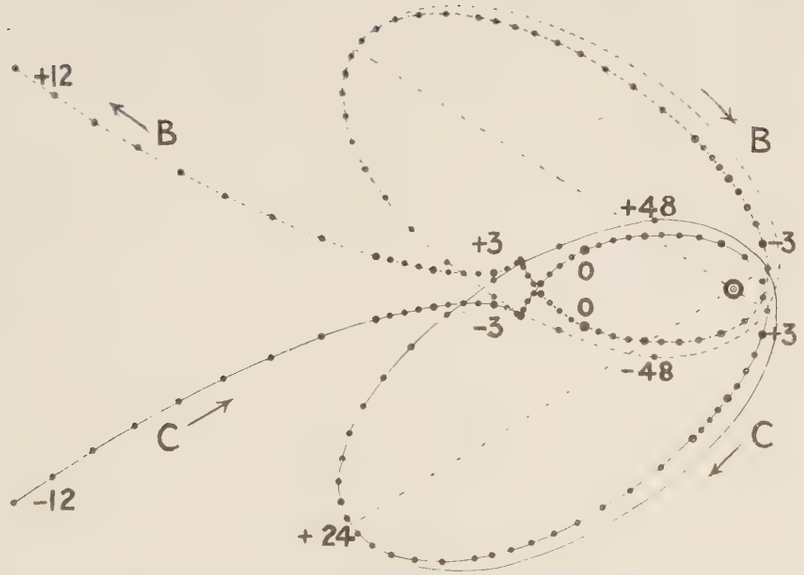
	B.	C.
ω	30°·1	202°·7
a	2·40	−3·50
e	0·935	1·078

ORBIT IV.

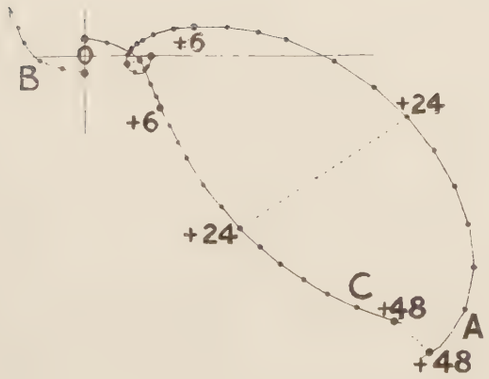
Time.	x 10^3.	y 10^3.	x' 10^3.	y' 10^3.	Time.	x 10^3.	y 10^3.	x' 10^3.	y' 10^3.
0·00	0	+1500	+3000	0	2·250	+4556	+1122	+2398	− 398
0·25	+ 575	1472	2991	+ 75	2·375	4640	1164	2553	544
0·50	1134	1394	2962	151	2·5	4721	1196	2703	672
0·75	1677	1284	2909	229	3	5054	1246	3263	1077
1·00	2206	1152	2829	309	3·5	5392	1222	3768	1375
1·25	2736	1007	2712	393	4	5732	1148	4229	1606
1·50	3284	852	2536	479	4·5	6072	1042	4652	1787
1·625	3580	774	2406	520	5	6414	908	5042	1928
1·750	3913	706	2207	542	6	7104	572	5731	2112
1·781	4010	700	2136	535	7	7806	+ 166	6307	2186
1·812	4116	708	2051	502	8	8534	− 303	6769	2162
1·844	4216	756	1974	412	9	9303	830	7105	2044
1·875	4276	815	1960	302	10	10140	1420	7284	1828
1·906	4314	866	1978	206	11	11106	2080	7222	1500
1·938	4342	908	2008	124	11·25	11384	2256	7144	1399
1·969	4366	942	2043	+ 52	11·50	11692	2440	7022	1286
2·000	4390	973	2080	− 13	11·75	12046	2644	6826	1140
2·125	+4474	+1062	+2239	−227	12	+12490	−2814	+6492	−1046

$t=+11·5$

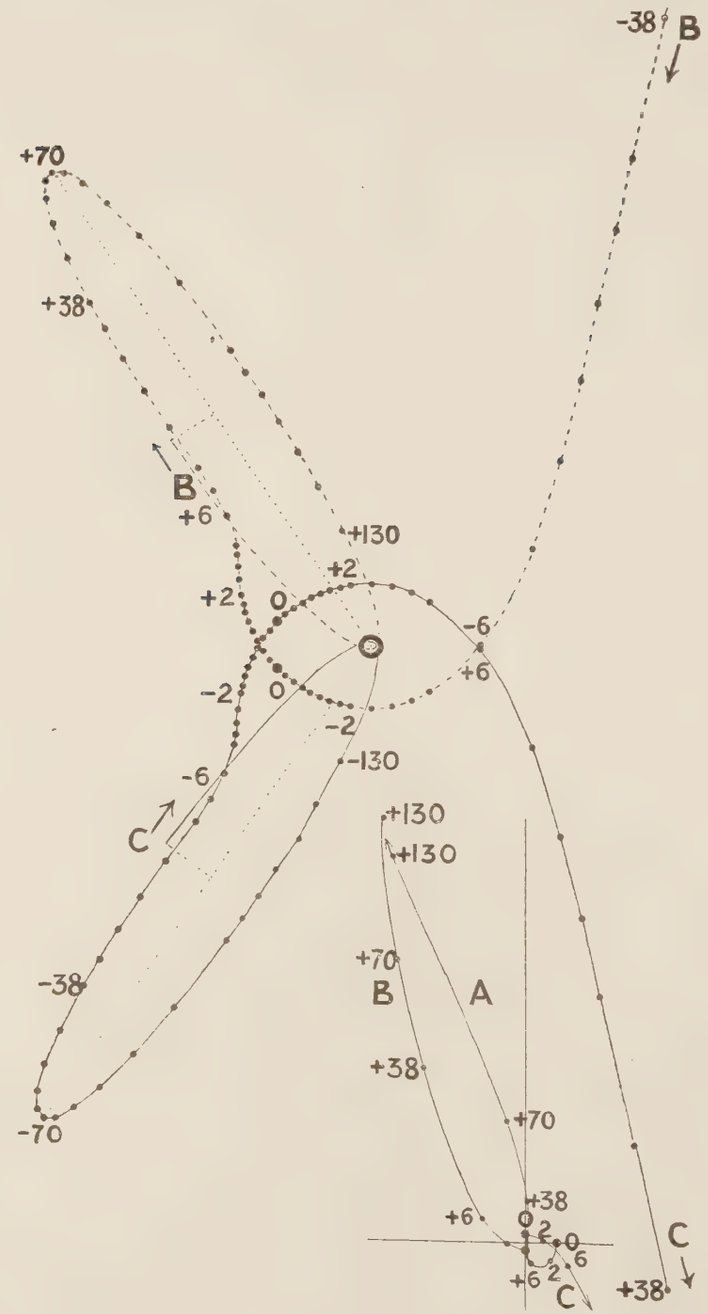
	C.	B.
ω	126°·9	315°·5
a	2·11	−36·7
e	0·869	1·024



ORBIT I. 1.



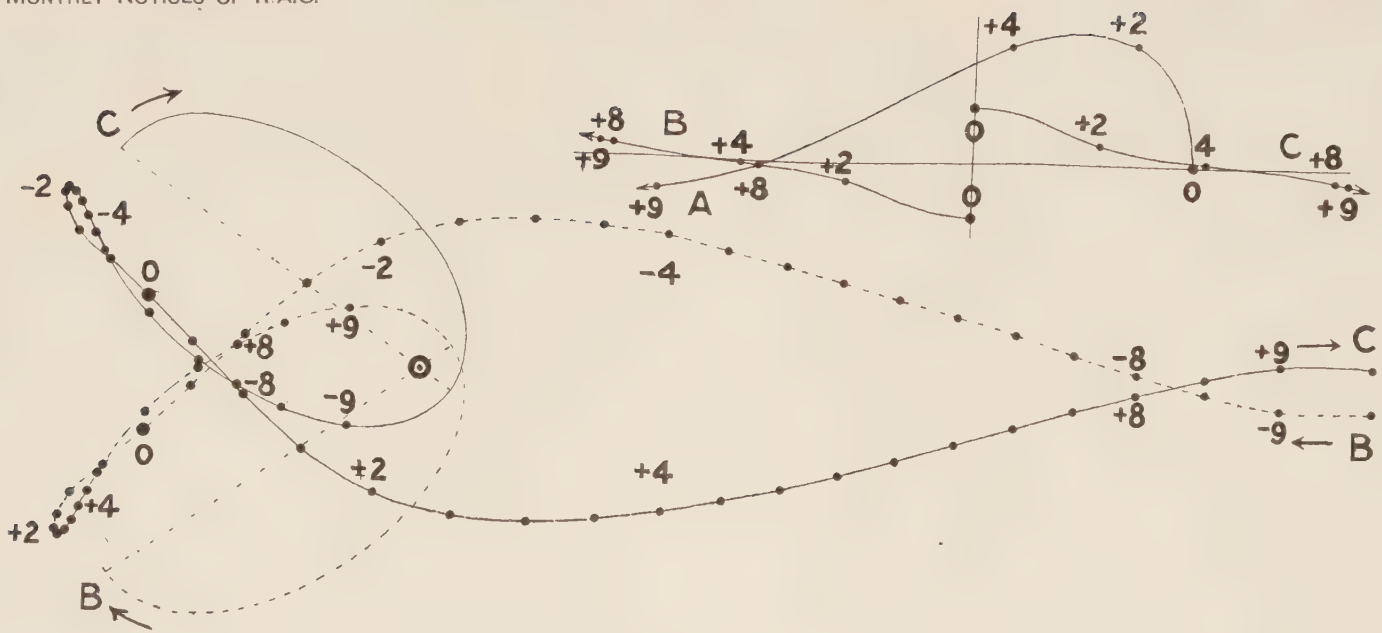
ORBIT I. 2.



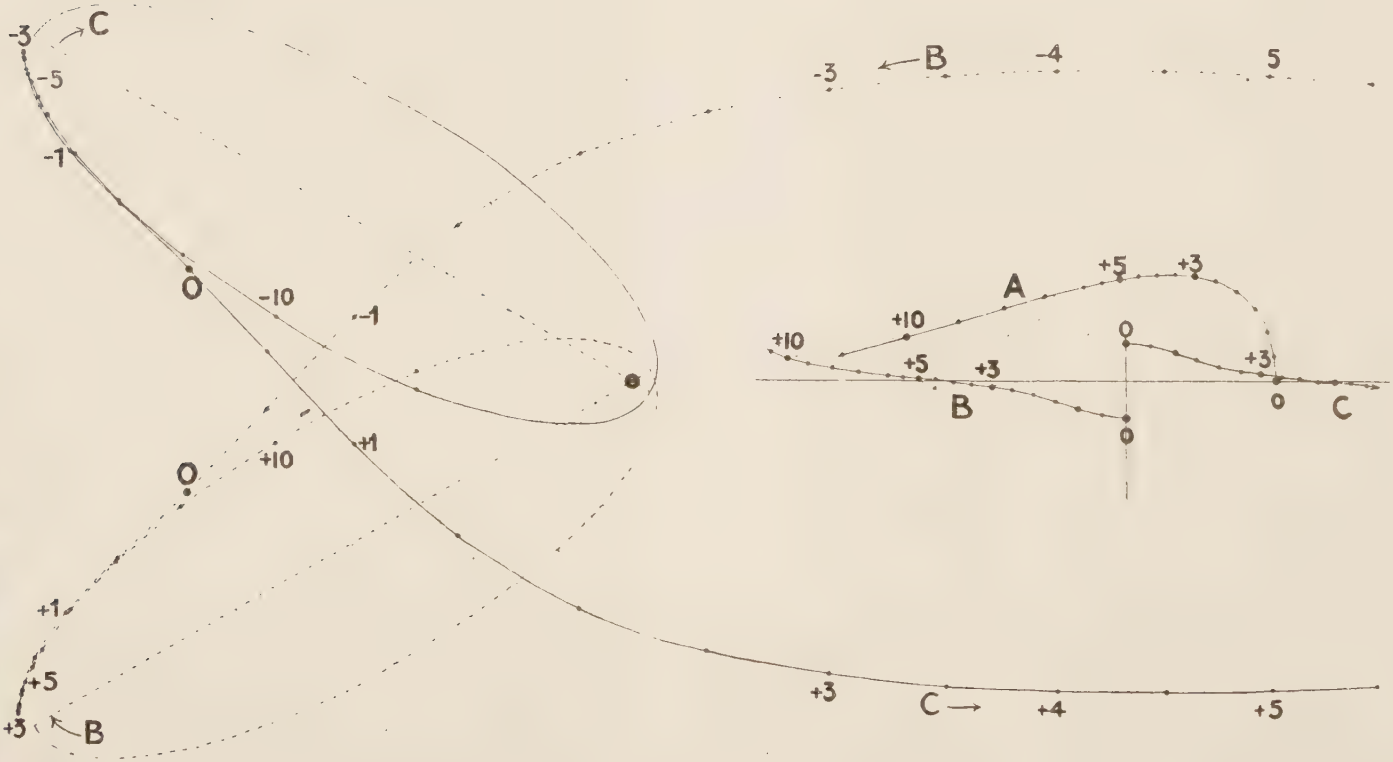
ORBIT II.

Tim
0
0
1
1
2
2
3
3
4

Ti
0
0
0
0
1
1
1
1
1
1
1
1
1
1
1
1
2
2

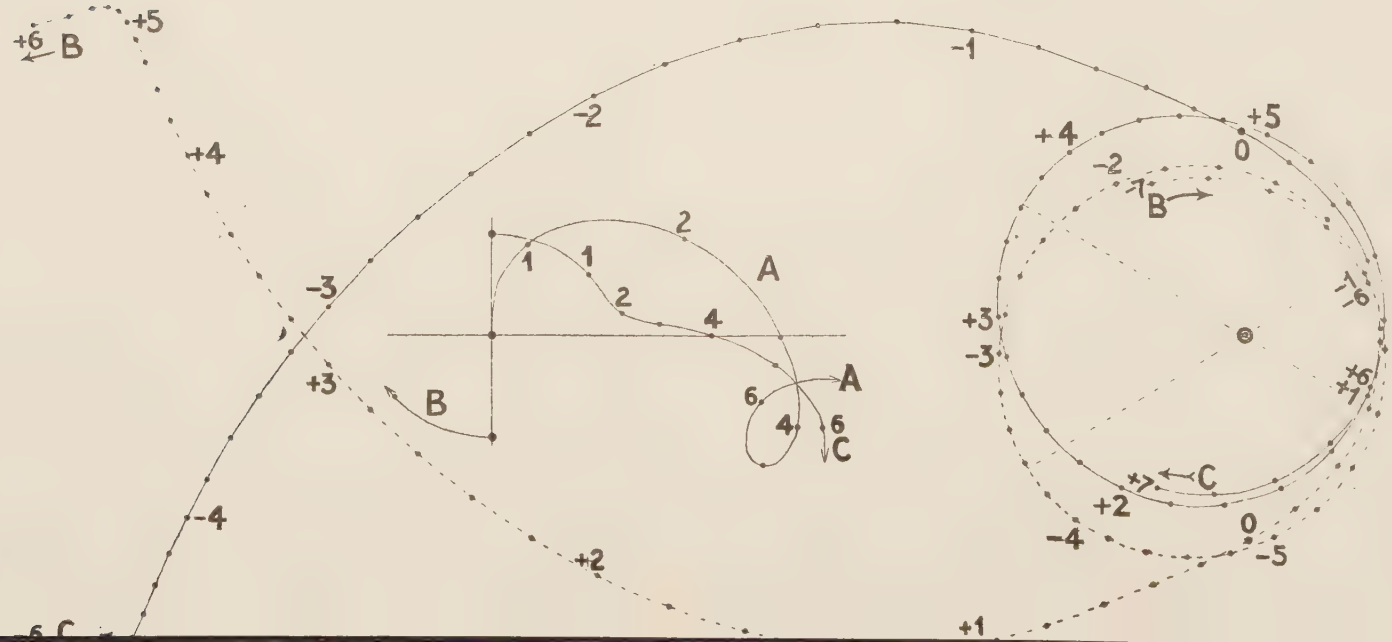


ORBIT III. 1



ORBIT III. 2.

ORBIT IV
A
B
C
+4
+6
+1
+2
+10
+12
-1
0
-2
-4
-6
-10
-12


ORBIT V.
A
B
C
+6
+5
+4
+3
+2
+1
-1
-2
-3
-4
-5
-6
0

ORBIT V.

Time $= \tau/200$

τ	x 10^4.	y 10^4.	x' 10^4.	y' 10^4.	τ	x 10^4.	y 10^4.	x' 10^4.	y' 10^4.
0	0	+3000	0	0	20	+3891	+650	+2881	+1441
0·5	+176	2997	0	+ 49	22	4073	559	3276	1213
1	352	2986	0	98	24	4273	492	3617	946
1·5	526	2969	0	148	26	4493	438	3903	654
2	700	2945	+ 1	201	28	4734	392	4136	348
2·5	871	2914	2	255	30	4995	343	4318	+ 38
3	1041	2876	5	311	32	5276	301	4452	− 269
3·5	1207	2832	9	371	34	5576	247	4541	567
4	1371	2780	16	433	36	5894	183	4588	849
4·5	1531	2723	26	499	38	6229	105	4595	1109
5	1686	2659	39	568	40	6579	+ 9	4567	1343
5·5	1836	2589	59	640	42	6943	− 107	4507	1546
6	1981	2514	81	716	44	7318	248	4419	1710
6·5	2120	2434	112	794	46	7703	417	4308	1830
7	2252	2350	149	875	48	8091	620	4180	1898
7·5	2377	2262	194	956	50	8479	862	4046	1908
8	2494	2172	247	1038	52	8856	1148	3920	1850
9	2706	1986	379	1199	54	9210	1482	3822	1717
10	2888	1801	544	1348	56	9519	1864	3782	1511
11	3043	1622	740	1477	58	9758	2283	3841	1248
12	3174	1455	960	1582	60	9905	2709	4033	972
13	3286	1302	1198	1657	62	9958	3097	4358	753
14	3386	1166	1446	1702	64	9950	3409	4771	646
16	3560	941	1950	1707	66	+9921	−3637	+5208	− 662
18	+3723	+773	+2435	+1613					

$t = +0{\cdot}31$

	C.	B.
ω	329°·9	282°·6
a	0·143	−2·27
e	0·303	1·101

The Capture Hypothesis of Binary Stars. By Professor L. Becker, Ph.D.

1. *The Hypothesis and the Results of Observations.*—When a star approaches a binary system it may on certain conditions be captured, and at the same time it may compel one of the components to leave the system. I have calculated some such capture orbits * on the assumption of equal masses for the three bodies. Similar effects will be produced when the masses are of the same order of magnitude.

According to this conception a binary system would, in the course of time, part with one of its components and receive another in its stead. It would thus be renewed at intervals. The hypothesis well accounts for the large eccentricities of the orbits.

The hypothesis can be put to a test. For each definite capture orbit another may be conceived which is its exact image and lies on the other side of the direction in which the new companion travelled before capture. Now, although the approach of a single star to a binary will not generally take place in the special manner considered, yet, if the direction of approach be parallel to a definite direction, the actual approaches should, on the average, be symmetrically placed with regard to the special conditions considered. Thus if a great number of binaries were approached by stars moving in parallel paths, the position of the ellipses after capture would be symmetrically arranged with reference to the common original direction of the paths. The Two-Star-Stream Theory assumes such common motion, and therefore our hypothesis demands that the major axes of the known binary stars should show symmetrical distribution with reference to the so-called *vertex* of the relative motion.

I have carried out the calculation for the known orbits of binary stars. The distribution of the directions of the major axes is actually found to be symmetrical with reference to a point whose R.A. is about 110°, and whose declination has a small positive value. This compares with R.A. 94° and decl. + 12° of the vertex,† towards and from which the streams move relatively to one another.

The calculations have further revealed a remarkable peculiarity in the distribution of the directions, which will be defined in the last section. This peculiar distribution does not appear to be demanded by the capture theory, and calls for detailed investigation of capture orbits before the theory can be accepted.

In the following sections I have explained the method by which I obtained the results.

2. *The Direction of the Major Axis on the Celestial Sphere.*—In the diagram of the Celestial Sphere round centre O, S is the heliocentric position of the star, and E the astrocentric position of the earth or sun. The great circle of which these points are the

* *M.N.* † A. S. Eddington, *Stellar Movements*, London, 1914.

poles is the reference plane in which the position angles are counted. Ω is the position angle of the node counted from great circle SPE, where OP is parallel to the earth's axis of rotation. The two great circles NM_1 and NM_2 drawn through N represent the planes of two orbits, N being the ascending node of the one and the descending node of the other orbit. The periastron M is at distance ω from the node counted in the direction of motion. Let α, δ denote the heliocentric right ascension and declination of

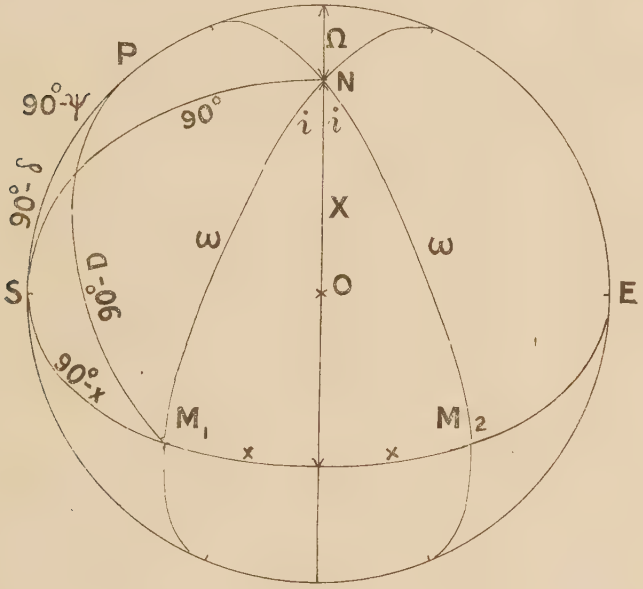


Fig. 1.

the star, and A, D the right ascension and declination of the periastron referred to the primary star, then

$$A = \alpha + 90^\circ - \psi,$$

where D and ψ are obtained from the spherical triangles SM_1N and SM_2P with the data i, ω, Ω, δ.

The same formulæ hold good for the descending node, provided that the negative value of the arc x be employed. The spherical angle at S in triangle SMP is $\Omega \pm X$, the upper sign belonging to increasing and the lower sign to decreasing position angles.

I carried out the calculations for 87 binary stars with the figures contained in Mr. Aitken's recently published book.* Instead of the elements of the eight binaries, Nos. 34, 35, 38, 43

* R. G. Aitken, *The Binary Stars*, New York, 1918, Table I.

No.	A.	D.	No.	A.	D.
	°	°		°	°
55	3	+27	5a	37	+14
25	3	+68	65	38	−30
5	4	− 1	39	41	+29
8	4	+16	61	42	−17
54	5	+12	61	42	−17
2	7	+30	36	45	−55
53	7	+32	43	45	+29
1a	7	+73	53	45	+ 8
31	7	+53	6a	46	+46
54	8	+14	51	46	−79
48	8	+26	40	47	−35
2	9	−51	41	47	− 7
37	10	+13	33	48	+46
44	12	−34	3	50	− 5
50	12	−26	3a	51	−20
7a	12	−28	11a	52	+25
48	12	+24	14a	52	+41
23	13	−62	14a	52	+41
1a	14	−27	10	53	+46
28	14	− 9	4a	53	+40
42	15	+60	18a	54	−20
3a	15	−79	20	54	−10
49	15	+ 8	66	54	−12
33	16	−73	27	57	+44
56	17	0	10a	57	+ 8
56	17	0	18a	57	+12
28	18	−27	30	57	+ 1
9a	19	+33	47	58	−48
24	21	+ 6	40	62	−18
46	21	+31	32	64	+26
68	22	+60	9	67	−30
38	23	+64	2a	69	+23
39	24	+68	11a	69	+55
65	27	− 9	52	70	+ 2
1	29	+19	12a	70	+68
7a	30	+68	4a	71	−21
63	30	+60	41	74	+28
62	30	+66	10	77	−61
15	31	+22	8a	77	− 1
6a	32	−22	14	79	+36
15a	33	− 4	67	79	+27
45	33	+27	4	79	−24
38	36	+37	1	81	−63
11	36	−26	31	82	−67

No.	A.	D.	No.	A.	D.
16_a	87°	+25°	46	126°	+15°
15	88	−75	52	126	+ 4
43	88	−33	4	128	− 2
7	92	+ 1	64	130	−41
9	94	−62	16	132	−23
62	94	+46	18	132	−72
17	95	− 9	18	132	−72
8	96	+60	26	135	+ 1
29	100	−42	13_a	138	−37
51	100	+21	42	139	−67
66	100	−16	14	140	+21
24	101	+55	59	142	+67
17_a	102	+32	27	142	+42
17_a	102	+32	19	143	+45
21	102	+21	3	145	+ 1
16	103	− 1	35	149	+ 5
57	104	−44	17	149	+32
47	105	−50	34	154	+ 6
8_a	105	+15	20	154	+68
16_a	105	+63	60	154	−18
5_a	105	+ 9	58	155	+35
34	106	− 3	29	155	− 4
67	106	+11	64	156	− 8
11	107	+54	22	158	−30
60	108	+29	22	160	−39
63	109	+ 4	36	162	−80
19_a	109	−63	58	162	+46
26	112	−47	49	162	− 4
44	114	+ 9	45	164	−56
23	115	+50	50	166	+25
12_a	115	+14	2_a	167	+20
19_a	119	− 7	68	168	+ 9
19	119	−32	30	169	+19
6	120	+ 5	59	169	+82
32	122	−67	12	170	+45
7	123	−27	55	171	−18
35	123	−18	13_a	172	+ 1
6	123	− 2	12	174	+44
13	124	+47	5	176	+63
13	124	+47	25	176	−28
10_a	124	+46	21	177	− 6
57	125	+ 7	15	178	+83
37	126	−50	9_a	179	−27

45, 1_a, 11_a, 18_a, I substituted corrected elements calculated by Mr. J. Jackson.* I calculated the directions of the major axes in both cases, the value of the position angle of the node being assumed to belong to both the ascending and the descending nodes. I therefore obtained 174 (twice 87) points on the Celestial Sphere, of which only 87 actually belong to binary stars. The other 87 positions falsify the results, and must be supposed to be distributed by chance. The table contains the results, the right ascensions and declinations (A and D) of the major axes being arranged in order of right ascension from 0° to 180°. The numbers are the same as in Aitken's Table I. All right ascensions between 180° and 360° have been decreased by 180° and the sign of their declinations reversed, as it is irrelevant which component is considered to be the primary.

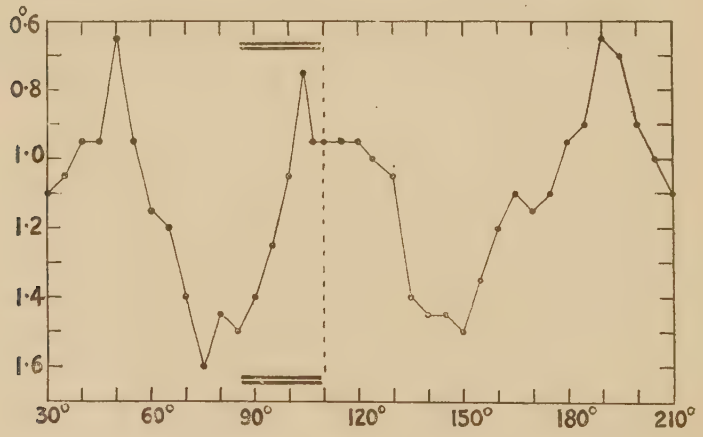


FIG. 2.

3. *On the Tabulated Results.*—With the object of getting the distribution in right ascension I noted at each position the number of degrees in right ascension occupied by 21 tabulated points, *e.g.* at No. 38, A = 23°, the 21 neighbouring points are Nos. 3_a to 45 at R.A. 15° to 33°, and hence their average distance in R.A. from each other is 0°·90. These average distances were combined into normal places for each fifth degree. They range from 0°·62 to 1°·52. In the diagram they are represented by the ordinates.

The curve is symmetrical about R.A. 110°. Two deep depressions are shown at a distance of about 30° from the line of symmetry. It is not clear on the basis of the capture hypothesis why these should occur at a distance of 30°. This point requires further consideration, as already stated in section 1.

The double line extending from R.A. 86° to 109° gives the range of values found for the R.A. of the vertex.†

The following summary gives an idea of the average declination

* *M.N.* † A. S. Eddington, *loc. cit.*, p. 124.

of the calculated points. Positive declinations preponderate, and near R.A. 110° a small positive value of the declination is indicated, in good agreement with the declination of the vertex, which the various determinations place between +3° and +28°.

Number of Points in Dec. Zones.

R.A. Zone.		−90 to −60.	−60 to −30.	−30 to 0.	0 to +30.	+30 to +60.	+60 to +90.	Total.
175° to	10°	...	1	4	7	2	4	18
10	25	3	1	6	4	4	2	20
25	40	...	...	5	4	2	2	13
40	55	1	2	8	4	6	...	21
55	70	...	1	2	6	2	...	11
70	85	3	...	3	2	1	1	10
85	100	2	2	1	2	2	...	9
100	115	1	3	3	8	5	1	21
115	130	2	2	5	5	3	...	17
130	145	3	1	1	3	2	1	11
145	160	...	1	4	2	2	1	10
160	175	1	1	2	5	3	1	13
Totals		16	15	44	52	34	13	174

Crieff:
1920 *February* 24.

The Variability of Es-Birm. 120 *Leporis.*

By Rev. T. E. Espin, M.A.

This star was announced by me as variable as far back as 1878. It is No. 137 in Gore's Catalogue of Suspected Variables, and a list of its magnitudes as estimated by various observers is given in the *E.M.*, 1886 January 15. It is No. 925 in the Harvard photometry, and in vol. xiv. part 2, p. 439, will be found Chandler's remarks upon it. In the Harvard photometric measures it has been recorded as high as 5·27 and as low as 6·30.

This season it was put on the list for observation. The instruments used were a powerful pair of field glasses, and a dumpy telescope with an aperture of $3\frac{1}{8}$ in. and a focal length of some 18 in. Observations were obtained on 32 nights from 1919 November 17 to 1920 March 23. The following comparison stars were used:—

Name.	R.A. 1900. h m s	Decl. ° ′	H.P. Magnitude.
A. 8 Leporis	5 18·9	− 14 1	5·17
B. ν Leporis	15·4	− 12 25	5·29
C. B.D. − 13°·1063	2·0	− 13 15	6·06
D. B.D. − 12°·1076	2·8	− 12 37	6·14

The star D was discarded as unsteady in light, and I subsequently found that I had suspected it previously as variable (*E.M.*, **28**, 473).

The Observations.

	h			h	
1919 Nov. 17		5·60	1920 Feb. 15	10 35	5·9
19		5·60	16	9 20	5·8
Dec. 8		5·5	17	7 50	5·8
12		6·0	22	9 40	5·7
16	11 0	5·8	26	6 50	5·2
1920 Jan. 8	8 0	6·10	27	6 50	5·2
17	10 20	6·10	Mar. 2	6 50	5·10
19	12 0	6·0	4	8 30	5·10
21	9 45	6·06	7	8 0	5·25
26	10 30	6·10	8	7 45	5·30
27	9 30	6·10	9	7 15	5·50
31	8 20	6·0	10	7 15	5·50
Feb. 4	7 0	5·9	17	7 30	5·90
8	10 0	5·9	18	8 10	6·00
10	10 45	5·8	22	7 30	5·90
11	8 0	5·8	23	7 30	5·90

The star therefore passed a maximum early in March.
The place of the variable for 1900 is :—

$$5^{h}\ 6^{m}\cdot7 - 11^{\circ}\ 58'.$$

On the Changes in Period of o (Mira) Ceti, S Herculis, and R Leonis.
By H. H. Turner, D.Sc., F.R.S., Savilian Professor.

In two previous papers it has been shown that the well-observed variables of long period offer by far the best, if not the only, chance of obtaining clues to the changes in period. From this point of view o Ceti, of which there are observed maxima as far back as 1596, is specially valuable. There is no doubt that the period has remained nearly the same for three centuries, since the value 331·6 days adopted at Harvard (*H.A.*, **55**, 120) gives residuals which never approach a half-period, but they cannot be treated as accidental. The following is offered as a provisional solution, there being opportunities for "breaks" or "jumps" at intervals of 20 cycles.

o Ceti 021403. Group II.

Adopted Period 331·6 − 1·0 *Days* = 330·6.

E.	Harv.	Calc.	H−C.	E.	Harv.	Calc.	H−C.
−298	+44	+31	+13	−218	−46	−49	+ 3
−284	− 8	+17	−25	−217	−52	−50	− 2
−251	−18	−16	− 2	−216	−56	−51	− 5
−228	−50	−39	−11	−215	−45	−52	+ 7
−227	−24	−40	+16	−209	−73	−58	−15
−226	−32	−41	+ 9	−208	−58	−59	+ 1
−225	−33	−42	+ 9	−207	−61	−60	− 1
−220	−31	−47	+16	−206	−74	−61	−13

It seems possible that there is a "break" at E = −225·5, in which case the subsequent period may be as small as 329·6 days.

From −205·5. *Adopted Period* 331·6 + 2·5 = 334·1 *Days.*

E.	Harv.	Calc.	H−C.	E.	Harv.	Calc.	H−C.
−204	−39	−66·2	+27	−182	− 2	−11·2	+ 9
−198	−74	−51·2	−23	−181	− 4	− 8·7	+ 5
−187	−45	−23·7	−21	−174	− 3	+ 8·8	−12
−186	−20	−21·2	+ 1	−172	+17	+13·8	+ 3
−184	− 9	−16·2	+ 7	−171	+17	+16·3	+ 1
−183	−11	−13·7	+ 3	−170	+12	+18·8	− 7

From −165·5. *Adopted Period* 331·6 + 0·5 = 332·1 *Days.*

−164	+11	+20·2	− 9	−151	+22	+26·7	− 5
−163	+22	+20·7	+ 1	−150	+39	+27·2	+12
−161	+27	+21·7	+ 5	−149	+19	+27·7	− 8

From −145·5. *Adopted Period* 331·6 + 0·7 = 332·3 *Days.*

−142	+ 5	−14·5	+20	−108	+23	+ 9·3	+14
−141	− 5	−13·8	+ 9	−107	+16	+10·0	+ 6
−126	−21	− 3·3	−18	− 96	+ 6	+17·7	−12
−121	−17	+ 0·2	−17	− 95	+ 9	+18·4	− 9
−120	0	+ 0·9	− 1	− 93	+17	+19·8	− 3
−119	+ 8	+ 1·6	+ 6	− 87	+33	+24·0	+ 9
−109	+14	+ 8·6	+ 5	− 86	+30	+24·7	+ 5

From −85·5. *Adopted Period* 331·6 − 0·3 = 331·3 *Days.*

E.	Harv.	Calc.	H−C.	E.	Harv.	Calc.	H−C.
− 85	+36	+36·8	− 1	− 60	+47	+29·3	+18
− 84	+34	+36·5	− 2	− 54	+17	+27·5	−11
− 83	+36	+36·2	0	− 53	+19	+27·2	− 8
− 77	+36	+34·4	+ 2	− 52	+18	+26·9	− 9
− 74	+30	+33·5	− 4	− 51	+16	+26·6	−11
− 73	+40	+33·2	+ 7	− 34	(−13)	+21·5	(−35)
− 65	+25	+30·8	− 6	− 33	(−14)	+21·2	(−35)
− 64	+17	+30·5	−13	− 30	+ 6	+20·3	−14
− 63	+28	+30·2	− 2	− 29	+32	+20·0	+12
− 62	+24	+29·9	− 6	− 28	+26	+19·7	+ 6
− 61	+41	+29·6	+11	− 27	+34	+19·4	+15

The brackets for E = −34 and −33 have been inserted here, and are not in the Harvard list. These two maxima are due to Bianchi, whose observations are given fully in *Ast. Nach.*, 15, 165, but in the present review of a large number of stars it has not been possible, except in rare instances, to go behind the Harvard tabulation: and during the early attempts to fit this tabulation to a consistent hypothesis, these two maxima of Bianchi were accepted as showing a notable break just before them, with a correction to period of about +7·0 days. There is such a long interval unobserved between E = −51 and E = −34 that it was not difficult to accept the break on any of a number of hypotheses which were tried. Thus, on the present hypothesis, there might be a break at E = −45·5. But the correction to period of +7·0 days or thereabouts, which must be accepted if the maxima from E = −34 to E = −27 are treated separately, would not come into line, whatever expedient was tried: and it was ultimately decided to try the effect of omitting these maxima, when everything else went smoothly. In this way something like a test of the hypothesis was provided: if, on referring to the original observations, good reason could be found for the Harvard date being about a month too early, the hypothesis would naturally be strengthened: if, on the other hand, the Harvard date stood the test of scrutiny, then not only the present discussion but others on similar lines would be undoubtedly shaken. It is now submitted that the former alternative is correct, and it seems worth while to give the details.

Bianchi's observations were not made by comparing the variable with other stars, but were direct estimates of magnitude in the illuminated field of a transit-circle. His claim to experience in such estimations may be fully admitted while still regarding the accidental error as large. Further, he formed the conclusion that the star shot up to maximum rather after the manner of a Nova, the highest peak being followed by a series of oscillations near it;

and he proposed to take the moment of the first (and highest) peak as that of maximum. Allowing something for the excitement at the first impression of brightness, this account is not inconsistent with what actually happens, as we now recognise it. The rise is rapid and there is a pause of a month or more near maximum, but we should regard the supposed oscillations as illusory and due to accidental errors (especially under the conditions related by Bianchi) rather than to real variations in brightness. We may now give the actual record, omitting the remarks on the weather, which do not seem to affect the conclusions:—

Date.	Mag.	Date.	Mag.	Date.	Mag.
1835 Dec. 12	10·11	1836 Dec. 10	6	1837 Jan. 27	5
1836 Jan. 5	10+	17	4·5	Feb. 1	4+
Feb. 1	3	22	4+	3	4+
6	5·6	26	3·4	7	3·4
9	5	30	3·4	26	5
11	6	1837 Jan. 3	4·5	Mar. 4	5
Nov. 9	9	4	4·5	8	6
25	8·9	8	5	10	6
Dec. 3	7·8	12	5	18	5
8	6	21	5		

Let us consider the second, and by far the better observed maximum. Harvard, **55**, enters the date Dec. 28 for it, midway between the two records of 3·4, and it is easy to see why this date was selected. But the magnitude 3·4 recurs on Feb. 7 and if the whole of the observations from Nov. 9 are plotted and compared with the curve of a modern well-observed maximum it is pretty easy to see that the date for maximum should be a good deal later than Dec. 28. My own estimate put it not earlier than Jan. 16. [The record was submitted also to the Rev. T. E. R. Phillips, who approves the general reasoning above.] As regards the earlier maximum, we see that the single record of Feb. 1, 1836, is not to be trusted as determining the maximum; and that the observations are consistent with a later maximum.

From −25·5. *Adopted Period* 331·6 + 2·0 = 333·6 *Days.*

E.	Harv.	Calc.	H−C.	E.	Harv.	Calc.	H−C.
−24	−16	−12·0	− 4	−13	+ 6	+10·0	− 4
−23	− 6	−10·0	+ 4	−12	0	+12·0	−12
−22	−10	− 8·0	− 2	−11	+22	+14·0	+ 8
−21	−14	− 6·0	− 8	−10	+26	+16·0	+10
−20	− 8	− 4·0	− 4	− 9	+12	+18·0	− 6
−19	+ 6	− 2·0	+ 8	− 8	+17	+20·0	− 3
−18	+15	0·0	+15	− 7	+24	+22·0	+ 2
−17	0	+ 2·0	− 2	− 6	+20	+24·0	− 4

From −5·5. *Adopted Period* 331·6 − 1·0 = 330·6 *Days.*

E.	Harv.	Calc.	H−C.	E.	Harv.	Calc.	H−C.
− 5	+19	+24·0	− 5	+ 6	+14	+13·0	+ 1
− 2	+10	+21·0	−11	+ 7	+19	+12·0	+ 7
− 1	+21	+20·0	+ 1	+ 9	+ 2	+10·0	− 8
0	+22	+19·0	+ 3	+10	+18	+ 9·0	+ 9
+ 1	+23	+18·0	+ 5	+11	+17	+ 8·0	+ 9
+ 2	+18	+17·0	+ 1	+12	+23	+ 7·0	+16
+ 3	+10	+16·0	− 6	+13	+ 2	+ 6·0	− 4
+ 4	+19	+15·0	+ 4	+14	0	+ 5·0	− 5
+ 5	+14	+14·0	0				

From +14·5. *Adopted Period* 331·6 + 2·2 = 333·8 *Days.*

+15	−18	−25·2	+ 7	+25	−18	− 3·2	−15
+19	−22	−16·4	− 6	+30	− 6	+ 7·8	−14
+20	−13	−14·2	+ 1	+31	+10	+10·0	0
+21	−12	−12·0	0	+32	+20	+12·2	+ 8
+22	− 8	− 9·8	+ 2	+33	+17	+14·4	+ 3
+23	− 4	− 7·6	+ 4	+34	+19	+16·6	+ 2
+24	−10	− 5·4	− 5				

From +34·5. *Adopted Period* 331·6 − 0·5 = 331·1 *Days.*

+35	+ 2	+ 6·0	− 4	+47	− 4	0·0	− 4
+36	+12	+ 5·5	+ 6	+48	− 2	− 0·5	− 1
+37	0	+ 5·0	− 5	+49	+ 4	− 1·0	+ 5
+41	−14	+ 3·0	−17	+50	− 3	− 1·5	− 2
+42	+ 4	+ 2·5	+ 1	+51	0	− 2·0	+ 2
+44	− 3	+ 1·5	− 5	+52	− 3	− 2·5	0

After E = 42 the residuals have been supplied by a provisional reduction of the B.A.A. observations.

Collecting the results the periods show an alternation as below :—

E.	Corrn. to Period. d	d	2 (Diff.) d	Corrected. d	Uniform.
−305·5 to −205·5	−1·0		(+6·2)	(+0·55)	0·0
−205·5 to −165·5		+2·5	+5·5	+1·1	+1·5
−165·5 to −145·5	+0·5		+2·2	+1·05	+1·5
−145·5 to − 85·5		+0·7	+1·2	+0·40	−0·3
− 85·5 to − 25·5	−0·3		+3·3	+0·50	+0·7
− 25·5 to − 5·5		+2·0	+5·3	+0·70	+1·0
− 5·5 to − 14·5	−1·0		+6·2	+0·55	0·0
+ 14·5 to + 34·5		+2·2	+5·9	+0·70	+1·2
+ 34·5 to ?	−0·5		(+3·0)	(+0·25)	+0·5

We may now examine the possibilities of secular change on various hypotheses.

(*a*) The column 2 (Diff.) is formed by comparing the double of any adopted correction with the sum of the two neighbouring corrections. Thus $2 \times 2{\cdot}5 - (0{\cdot}5 - 1{\cdot}0) = 5{\cdot}5$. These numbers suggest an oscillation, and if we accept it we can fill in the first and last approximately as shown in brackets. Correcting the successive periods then by one quarter of this column, taken alternately with + and − sign, we get the numbers in the column "corrected." The means of first 4 and last 4 are $0^d{\cdot}78$ and $+0^d{\cdot}55$. Omitting the first and last as uncertain (in correction) the means of the other 3 are $+0^d{\cdot}82$ and $+0^d{\cdot}65$.

(*b*) If we assume that the appearance of oscillation in the difference is illusory and that it is really constant, the mean value is $+4{\cdot}2$, giving a mean correction of $+1{\cdot}0$ day. Applying this we get the column "uniform": mean of first four $+0{\cdot}68$ of last four $+0{\cdot}68$, exactly equal. There is now not the same reason for excluding the first and last, but if we do so the means are $+0{\cdot}90$ and $+0{\cdot}73$.

(*c*) If we ignore the alternation and take means of first four and last four we get the same result as in (*b*), viz. 0·68 in each case.

There is thus no suggestion of a secular *increase* of period; but whether there is any decrease is doubtful. It will be seen that there would be a fair case for a slight decrease on almost any hypothesis if it were not for the first group, and the question arises whether the value for this group can be revised: but if we accept the figures given above, any revision will make the period *smaller* and not larger. If for instance we stop at $-225{\cdot}5$ (in going backwards) we get, as already remarked, a correction $-2{\cdot}0$ instead of $-1{\cdot}0$. If we stop at $-245{\cdot}5$ we get $-1{\cdot}5$. The future behaviour of the star may throw some light on this early group, but at present it seems as though the period were then less than it has ever been subsequently, though since $E = -205{\cdot}5$ a good case could be made out for gradual decrease.

The numerical means of the residuals in the above groups stand as follows:—

E.	No. Res.	Mean.	E.	No. Res.	Mean.
−220	16	±9·2	−15	16	±6·1
−185	12	±9·8	+ 5	17	±5·6
−155	6	±7	+25	13	±5·2
−115	14	±9·6	+45	12	±4·3
− 55	20	±7·8			

In the group $-85{\cdot}5$ to $25{\cdot}5$, Bianchi's two observations have been omitted. If we include them the mean residual is ±10·4. After $E = -30$ there is a notable increase in the number of determinations at each maximum (of which the mean is taken for entry above), which largely accounts for the diminution in mean residual.

Before leaving this star it is desirable to note the "jumps," or abrupt changes in phase, implied in the above solution. We may assume, as a first approximation, that these take place at $-205{\cdot}5$, $-165{\cdot}5$, etc. Calculating then the residuals for the preceding and following groups at these points, the difference gives the "jump."

E.	Preceding.	Following.	Jump.	Adopt.
$-205{\cdot}5$	$-61{\cdot}5$	$-70{\cdot}0$	$-8{\cdot}5$	$-10{\cdot}4$
$-165{\cdot}5$	$+30{\cdot}4$	$+19{\cdot}5$	$-10{\cdot}9$	$-10{\cdot}4$
$-145{\cdot}5$	$+29{\cdot}4$	$-17{\cdot}0$	$-46{\cdot}4$	$-41{\cdot}6$
$-85{\cdot}5$	$+25{\cdot}0$	$+37{\cdot}0$	$+12{\cdot}0$	$+10{\cdot}4$
$-25{\cdot}5$	$+19{\cdot}0$	$-15{\cdot}0$	$-34{\cdot}0$	$-31{\cdot}2$
$-5{\cdot}5$	$+25{\cdot}0$	$+24{\cdot}5$	$-0{\cdot}5$	$0{\cdot}0$
$+14{\cdot}5$	$+4{\cdot}5$	$-26{\cdot}3$	$-30{\cdot}8$	$-31{\cdot}2$
$+34{\cdot}5$	$+17{\cdot}7$	$+7{\cdot}2$	$-10{\cdot}5$	$-10{\cdot}4$

We thus have one jump sensibly zero: four have values $-8{\cdot}5$, $-10{\cdot}9$, $+12{\cdot}0$, $-10{\cdot}5$, and should possibly all have the same numerical value (say $\pm 10{\cdot}5$); two others, $-34{\cdot}0$ and $-30{\cdot}8$, should possibly both be three times this unit (say $\pm 31{\cdot}5$, which is near their mean value), and there remains $-46{\cdot}4$, the relation of which to the others is not clear. It follows the shortest and therefore most uncertain group of all, and inspection of the collected periods suggests that their adopted correction of $+0{\cdot}5$ is too large and should be reduced to zero or even negative. Taking a zero value for illustration, the mean residual for the group is $+23{\cdot}3$, which, combined with $-17{\cdot}0$, would give $-40{\cdot}3$, close to the multiple $4\times 10{\cdot}5$. At the same time we should reduce the preceding jump to $-6{\cdot}9$ and thus reduce the unit. We may thus reasonably take the jumps as in the column "Adopt," and the periods can then be deduced if we assume that the mean residual for the group is to remain undisturbed. Approximately this condition is fulfilled if we alter the terminal calculated residuals equally in opposite directions. Thus the following would be a solution observing the canons indicated.

Hypothetical Solution.

E.	Preceding.	Following.	Jump.	Period.
				d
				Preceding $= -1{\cdot}00$
$-205{\cdot}5$	$-61{\cdot}0$	$-71{\cdot}4$	$-10{\cdot}4$	$+103{\cdot}2/40 = +2{\cdot}58$
$-165{\cdot}5$	$+31{\cdot}8$	$+21{\cdot}4$	$-10{\cdot}4$	$-\ 0{\cdot}2/20 = -0{\cdot}01$
$-145{\cdot}5$	$+21{\cdot}2$	$-20{\cdot}4$	$-41{\cdot}6$	$+\ 48{\cdot}8/60 = +0{\cdot}81$
$-85{\cdot}5$	$+28{\cdot}4$	$+38{\cdot}8$	$+10{\cdot}4$	$-\ 21{\cdot}6/60 = -0{\cdot}36$
$-25{\cdot}5$	$+17{\cdot}2$	$-14{\cdot}0$	$+31{\cdot}2$	$+\ 38{\cdot}0/20 = +1{\cdot}90$
$-5{\cdot}5$	$+24{\cdot}0$	$+24{\cdot}0$	$0{\cdot}0$	$-\ 19{\cdot}0/20 = -0{\cdot}95$
$+14{\cdot}5$	$+5{\cdot}0$	$-26{\cdot}2$	$+31{\cdot}2$	$+\ 43{\cdot}8/20 = +2{\cdot}19$
$+34{\cdot}5$	$+17{\cdot}6$	$+7{\cdot}2$	$+10{\cdot}4$	Following $= -0{\cdot}50$

But though in this way we see that the star may easily be brought within the general rules suggested by other stars the main question of secular change of period is not touched and must be left to the future to decide.

The main conclusion then for this Group II. star is that there is an alternation of rather longer and shorter periods, the changes taking place at multiples of 20 cycles, but that no clear secular change of period may be regarded as established, though there is some indication of a small decrease on the whole.

S Herculis 164715. *Group I.*

This star was discussed by Phillips (*M.N.*, **75**, 562), and by Miss Blagg and the writer (*M.N.*, **76**, 185) from Phillips's material. It is quoted in the paper on W Cygni (*M.N.*, **80**, 58) as an instance of a period oscillating with secular increase. Referring the figures there given to the Harvard adopted value 308·3 days, instead of Phillips's 306·2, we get

E =	1	13	48	70
Error of Epoch	+72	−29	+38	−118 days
Correction to Period	−8·4	+1·9	−7·1	,,
Period	299·9	310·2	301·2	,,

Phillips did not, however, use all the material given in *H.A.*, **55**, so that a further discussion is desirable; but it can be given very briefly. We will refer everything to the adopted Harvard period of 308·3 days. Breaks are suggested at E = +49·5 and E = +20, and thus by inference at E = −9·5. The two earliest maxima at E = −19 and E = −12 (residuals −43 and −16) belong almost certainly to a separate group of cycles. Moreover they are not observed maxima of the usual kind, but merely inferences that the star was bright from its being observed on the meridian at Greenwich (*A.J.*, **8**, 174). We may thus ignore them for the present.

The residual for E = 29 is printed as −12 in *H.A.*, **55**, 198, but is apparently an error for −2. With this exception the Harvard residuals are given in the column H, those of Phillips (*M.N.*, **75**, 563) under heading P.

The mechanical process applied to the H residuals gives the correction −6·5 days. Applied to the P residuals we obtain, whether we include or exclude those in brackets, −8·0 days. The effect of both these suppositions is shown; first under C_1 the correction obtained from the P (and presumably better determined maxima) and then under C_2, the longer period.

The main point at issue is whether this initial period was or was not smaller than the present period. On the evidence of the P maxima it was, though not perhaps so decidedly as formerly represented. But the H maxima tend to upset this result, as will be seen presently.

S Herculis. C_1 *Adopted Period* 308·3 − 8·0 *Days* = 300·3 *Days.*
„ C_2 „ 308·3 − 6·5 „ = 301·8 „

E.	H.	P.	C_1.	H−C_1.	P−C_1.	C_2.	H−C_2.	P−C_2.
0	+65	...	+79	−14	...	+67·2	− 2	
1	...	+64	+71	...	−7	+60·7	...	+ 3
2	...	(+63)	+63	...	(0)	+54·2	...	(+ 9)
3	+50	+56	+55	− 5	+1	+47·7	+ 2	+ 8
6	...	+31	+31	...	0	+28·2	...	+ 3
7	...	+21	+23	...	−2	+21·7	...	− 1
8	...	+15	+15	...	0	+15·2	...	0
9	...	(+11)	+ 7	...	(+4)	+ 8·7	...	(+ 2)
10	+11	0	− 1	+12	(+1)	+ 2·2	+ 9	− 2
11	...	(−16)	− 9	...	−7	− 4·3	...	(−12)
12	−11	−22	−17	+ 6	−5	−10·8	0	−11
13	−21	(−25)	−25	+ 4	(0)	−17·3	− 4	− 8
14	−42	...	−33	− 9	...	−23·8	−18	
18	−45	...	−65	+20	...	−49·8	+ 5	
19	−55	...	−73	+18	...	−56·3	+ 1	

The period now changes definitely and considerably, as will be seen from Phillips's diagram in *M.N.*, 75, 563. It will also be seen that there is a question whether to regard the portion E = 21 to E = 49 as a whole or to break it up. It was first treated as a whole. The correction to period given by the P figures was +1·5 days. The H maxima gave +2·5 days or +2·0 days, according as the result for E = 21 (possibly affected by the jump) was included or excluded. Adopting +1·5 days for trial it became clear that there was a systematic difference of several days between P and H. Now Phillips has after some hesitation applied a correction of +6 days, to the Rousdon observations from E = 37 to E = 52. Removing this removed the discrepancy in this part of the record, but it left even more clearly a difference of P − H = +10 days from E = 26 to 34. This portion is (in P) Baxendell's *second* series of observations after a break of 13 cycles, and it is thus indicated that Baxendell differed systematically by 10 days from his former practice [a mistake in computation of 10 days was looked for without success]. This correction has been applied below. Moreover it becomes clearer than ever that there is a difference of period between the first half (E = 21 to 34) and the second half (E = 37 to 49). Note that the break comes just half way between the two at E = 20·5 and 49·5, as nearly as we can tell from the evidence.

S Herculis. Adopted Period 308·3 + 3·7 = 312 *Days.*

E.	H.	P−10.	C.	H−C.	P−C.	E.	H.	P−10.	C.	H−C.	P−C.
21	−29	...	−33·0	+ 4		30	...	(0)	+ 0·3	...	0
24	−12	...	−21·9	+10		31	− 4	...	+ 4·0	−8	
26	...	(−15)	−14·5	...	0	32	+ 2	...	+ 7·7	−6	
27	−15	(−10)	−10·8	− 4	+1	33	+10	+14	+11·4	−1	+3
28	− 8	...	− 7·1	− 1		34	+21	+18	+15·1	+6	+3
29	− 2	−10	− 3·4	+ 1	−7						

The Adopted Period is now 308·3 + 1·5 = 309·8 *Days.*

E.	H.	P−10.	C.	H−C.	P−C.	E.	H.	P−10.	C.	H−C.	P−C.
37	+12	(+19)	+12·8	− 1	(+6)	44	+20	(+28)	+23·3	−3	(+5)
38	+16	+14	+14·3	+ 2	0	45	+26	(+29)	+24·8	+1	+4
39	+18	+ 7	+15·8	+ 2	−9	46	+27	+26	+26·3	+1	0
40	+31	+13	+17·3	+14	−4	47	+29	+28	+27·8	+1	0
41	...	(+10)	+18·8	...	(−9)	48	...	(+28)	+29·3	...	(−1)
42	...	+17	+20·3	...	−3	49	...	+28	+30·8	...	−3
43	...	+23	+21·8	...	+1	50	+19	0	+32·3		

We now come to the return to a small period, and the question is whether it is so small as at first. There is the preliminary question whether to treat the remaining maxima in one group or two. Phillips's diagram gives some indication of a change and we have already found that the interval between breaks is not 29 cycles but half that value, which indicates liability to a break at about E = 49·5 + 14·5 = 64. Now the first discussion, treating the material as a whole, showed a change just after 64. There are no H residuals, but the P residuals after 64 were all negative and numerically increasing. It seems advisable therefore to deduce the period from the portion E = 50 to 64. The P residuals give −5·3 days, but the H give −7·0 days. As at first it seems well to exhibit both these hypotheses.

Adopted Period $C_1 = 308·3 - 5·3 = 303·0$; $C_2 = 308·3 - 7·0 = 301·3$.

E.	H.	P.	C_1.	H−C_1.	P−C_1.	C_2.	H−C_2.	P−C_2.
50	+19	(+ 0)	+10·3	+ 9	−10	+ 21	− 2	−21
51	+10	+ 2	+ 5·0	+ 5	− 3	+ 14	− 4	−12
52	+12	+ 12	− 0·3	+12	+12	+ 7	+ 5	+ 5
53	− 6	...	− 5·6	0	...	0	− 6	
54	− 4	...	−10·9	+ 7	...	− 7	+ 3	
55	−28	...	−16·2	−12	...	− 14	−14	
56	−32	...	−21·5	−10	...	− 21	−11	
57	−31	...	−26·8	− 4	...	− 28	− 3	
58	−36	− 29	−32·1	− 4	+ 3	− 35	− 1	+ 6
59	−44	− 43	−37·4	− 7	− 6	− 42	− 2	− 1
60	−34	− 45	−42·7	+ 9	− 2	− 49	+15	+ 4
61	...	− 49	−48·0	...	− 1	− 56	...	+ 7
62	−76	− 59	−53·3	−23	− 6	− 63	−13	+ 4
63	...	− 59	−58·6	...	0	− 70	...	+11
64	...	− 64	−63·9	...	0	− 77	...	+13
65	...	− 79	−69·2	...	−10	− 84	...	+ 5
66	...	− 93	−74·5	...	−18	− 91	...	− 2
67	...	− 99	−79·8	...	−19	− 98	...	− 1
68	...	−106	−85·1	...	−21	−105	...	− 1
69	...	−113	−90·4	...	−23	−112	...	− 1

Consider first C_2. It was deduced from the H maxima and naturally suits them: the residuals would look better still if we added a constant +3·0 days. But it clearly does not suit the P maxima either near E = 50 or E = 64. On the other hand C_1 suits P of course; it suits H with the one exception of E = 62 (which is a single provisional estimate by Grover), and it brings out clearly the break at 64·5. But from 65 onwards the period is at least as small as 308·3 − 7·0 days if not smaller—we can scarcely tell until we get more observations; so that the main question whether there has been a secular increase is for the present left in doubt.

There seems to be no doubt that "breaks" are liable to occur about every 15 cycles. Provisionally we may put them at E = 64·3, 45·9, 34·7, 19·9, (5·1); and this raises the question whether the first group is really homogeneous. The only reasonable test we can apply is to determine the period from the residuals subsequent to E = 5 only; but the values so found, both for the H and P series, are so close to their former ones that it seems probable there was no change at this opportunity.

Summarising therefore we have—

E=0	19·9	34·7	49·5	64·3	
Correction	−8·0 or −6·5	+3·7	+1·5	−7·0 or −5·3	−7·0?
Period	300·3 or 301·8	312·0	309·8	301·3 or 303·0	301·3?

R Leonis 094211. *Group I.* (*Phillips*), *II.* (*Turner*).

Preliminary study of the residuals tabulated in *H.A.*, 55, 151, suggested "breaks" at E = 94·5, (110·7), 126·9, 143·1, 159·3, 175·5, which have been adopted below, omitting that in brackets, at which apparently no change occurred. The eight maxima recorded before E = 94·5 cannot therefore be profitably discussed at present, as never more than two fall in the same group.

Alongside the maxima recorded (*loc. cit.*) which are in column H, column B + 8 gives the Baxendell maxima carefully discussed in *M.N.*, 76, 169, with an arbitrary addition of 8 days which seems necessary to reduce them to accord with H. Since the precise place of the maximum was arbitrarily assigned for Baxendell's rather scanty records, the change is of little importance and may be compared with a similar necessity for the preceding star S Herculis. Such changes do not affect the inferred periods, so long as the observations concerned are kept separate.

After E = 150 when the Baxendell observations run out, a few maxima from observations at Harvard were used in the former discussion (*loc. cit.*). They agree quite well with others, but it seems better now to substitute the excellent B.A.A series from E = 167. The readings are approximate and provisional only, but quite sufficient for the present purpose, as they make clear a totally new departure after E = 175.

R Leonis. Adopted Period 312·8 − 0·6 = 312·2 *Days.*

E.	H.	B+8.	C.	H−C.	B−C.	E.	H.	B+8.	C.	H−C.	B−C.
97	0	...	− 2·0	+ 2		116	...	−13	−13·4	...	
105	−12	...	− 6·8	− 5		117	−15	...	−14·0	− 1	
106	−17	...	− 7·4	−10		118	−14	−13	−14·6	+ 1	+ 2
107	+ 1	+ 6	− 8·0	+ 9	+14	119	−13	−14	−15·2	+ 2	+ 1
108	− 8	...	− 8·6	+ 1		120	−18	−19	−15·8	− 2	− 3
110	...	− 6	− 9·8	...	+ 4	121	−18	...	−16·4	− 2	
111	−16	...	−10·4	− 6		123	...	−18	−17·6	...	0
112	−15	− 8	−11·0	− 4	+ 3	124	−13	−20	−18·2	+ 5	− 2
113	−11	−12	−11·6	+ 1	0	125	−22	−19	−18·8	− 3	0
114	− 7	...	−12·2	+ 5		126	−19	−18	−19·4	0	+ 1
115	− 9	...	−12·8	+ 4		127	− 7	−19	−20·0	+13	+ 1

Adopted Period 312·8 + 0·8 = 313·6 *Days.*

127	− 7	−19	−12·4	+ 5	− 7	135	− 5	...	− 6·0	+ 1	
128	−16	...	−11·6	− 4		136	+ 2	...	− 5·2	+ 7	
129	−24	...	−10·8	−13		138	+ 1	...	− 3·6	+ 5	
131	−10	...	− 9·2	− 1		139	+ 2	...	− 2·8	+ 5	
132	− 4	...	− 8·4	+ 4		140	− 3	...	− 2·0	− 1	
133	− 4	+ 1	− 7·6	+ 4	+ 9	141	− 8	...	− 1·2	− 7	
134	− 7	...	− 6·8	0		142	0	+ 5	− 0·4	0	+ 5

Adopted Period 312·8 + 0·8 = 313·6 *Days.*

144	...	+13	+15·4	...	− 2	150	...	+20	+20·2	...	0
146	+12	...	+17·0	− 5		153	+25	...	+22·6	+ 2	
147	+18	+15	+17·8	0	− 3	154	+31	...	+23·4	+ 8	
148	+15	+19	+18·6	− 4	0	155	+26	...	+24·2	+ 2	
149	+19	...	+19·4	0		159	+11	...	+27·4	−16	

Adopted Period 312·8 − 1·8 = 311·0 *Days.*

E.	H.	B.A.A.	C.	H−C.	B.A.A.−C.	E.	H.	B.A.A.	C.	H−C.	B.A.A.−C.
160	+ 1	...	− 7·8	+ 9		169	−35	−25	−24·0	−11	− 1
161	−13	...	− 9·6	− 3		170	−33	−28	−25·8	− 7	− 2
162	−13	...	−11·4	− 2		172	−42	...	−29·4	−13	
163	−12	...	−13·2	+ 1		173	−42	−31	−31·2	−11	0
164	...	...	−15·0	...		174	−34	−34	−33·0	− 1	− 1
166	−18	...	−18·6	+ 1		175	−27	−32	−34·8	+ 8	+ 3
167	−24	−20	−20·4	− 4	0	176	+15	−25	−36·6	+52	+12
168	−22	−22	−22·2	0	0	177	...	−18	−38·4	...	+20

After E = 175 the B.A.A. observations make it abundantly clear that the period has *increased* considerably, say by six days. The following were read off by a summary process and are subject to revision when a definitive reduction of these excellent observations is made: but they suffice to establish the main point.

E.	B.A.A.	B.A.A.−H.	C.	B.A.A.−C.	E.	B.A.A.	B.A.A.−H.	C.	B.A.A.−C.
176	7935	−25	−25	0	180	9215	+ 4	− 1	+5
177	8255	−18	−19	+1	181	9530	+ 6	+ 5	+1
178	8570	−15	−13	−2	182	9843	+ 7	+11	−4
179	(8890)	− 8	− 7	−1	183	0165	+18	+17	+1

This quite upsets the idea of alternation with slow secular *decrease* of period formerly suggested (*M.N.*, **80**, 58, and **78**, 539). The revised figures are—

E =	94·5	126·9	143·1	159·3	175·5	
Corrn. to Period.	−8·6	+0·8	+0·8	−1·8	+6·0	days
Period.	312·2	313·6	313·6	311·0	318·8	,,

Of course the period may ultimately diminish, but at present it has the appearance of a considerable increase. It is perhaps relevant that Phillips originally placed this star in Group I. on the evidence of ϕ_3; it was removed to Group II. by the writer since $\phi_2 = 114°$, which lies between 90° and 270°. The excess over 90° is not large and revision may conceivably reduce it; or the value of ϕ_3 may after all be a preferable criterion. But in terms of the present provisional reduction the star goes the wrong way.

Summary.

Three well-observed stars have been examined for changes of period, with the result that the evidence accumulated for the hypothesis "Group II. decreasing, Group I. increasing" has certainly not been strengthened.

o Ceti (Group II.), observed since 1596, shows eight changes of period, but of an oscillatory character; giving no certain secular change.

S Herculis (Group I.), already quoted as an instance of oscillation with secular increase, is found not to be certainly increasing, though the evidence is consistent with an increase.

R Leonis (Group I., Phillips; Group II., Turner), already quoted as an instance of oscillation with secular decrease, has recently increased in period by an amount much greater than the former changes. To accord with the hypothesis it should perhaps be returned to Group I.

But from another point of view the examination is satisfactory. The discussion of R Hydræ started the idea of changes of period or phase or both at regular intervals, which has been found to suit other stars; and these three well-observed stars fall in with this suggestion. The unit intervals are—

Star.	*o* Ceti.	S Herculis.	R Leonis.
No. Cycles	20	15	16
No. Days	6600	4600	5000

Note on the 240-Year Period in Chinese Earthquakes in the Light of Dr. Fotheringham's Paper. By H. H. Turner, D.Sc., F.R.S., Savilian Professor.

1. In *Monthly Notices*, **79**, 531 (May 1919) a period of 240 years in Chinese earthquakes was suggested, and the question was raised whether the long-period term in the Moon's longitude might not be of this length. At my request Dr. Fotheringham undertook a new discussion of lunar observations and found that, though the assumption of 240 years for the period would not give impossible results, the associated values obtained for the secular acceleration pointed rather to a period nearer 260 years. Of this conclusion he has now found striking confirmation as sketched in the note on p. 578; and it is natural to enquire how far the longer period will suit the Chinese earthquakes and other phenomena for which we have data. The answer is favourable to the view that 260 years, or something near it, will suit all the phenomena.

2. Taking first the Chinese earthquakes, the Fourier sequence given in Table I. (*loc. cit.*) points to a period very near 262 years. Perhaps too much importance was given to the change of sign which follows it. But the main reason for reducing the value to 240 years is to be found in Table IV., where the phases for consecutive cycles are brought into accord by this shortening. If we lengthen the period to 260 years, we do not get so good an accordance. On this evidence alone therefore the period would be 240 years or thereabouts.

3. But we can easily try the effect of assuming 260 years as the period by rearranging the 10-year sums of Table II. We can only get six complete cycles, and we will omit the first three terms and the last three.

4. It is seen at a glance that the earthquake activity is specially great in 60 years out of the 260; and that this is the case in nearly every cycle. For the other 200 years the mean activity is nearly constant. Carrying on the cycle, the critical 60 years recurred in 1720–1780 and will come again in 1980–2040; so that we have still 60 years to run before the end of a quiescent period.

TABLE I.

Chinese Earthquakes: Revised Cycle of 260 Years.

Date.	60.	320.	580.	840.	1100.	1360.	Total.
10	1	5	3	6	1	26	42
30	5	11	2	8	10	4	40
50	16	11	3	4	6	7	47
70	15	10	9	0	12	14	60
90	13	6	2	6	10	5	42
110	11	2	6	2	11	22	54
130	2	1	4	1	3	38	49
150	0	3	3	2	3	47	58
170	5	1	1	17	2	14	40
190	5	1	4	8	7	20	45
210	7	5	30	12	35	27	116
230	28	5	5	14	33	28	113
250	11	3	6	15	36	24	95

5. We now turn to the Nile floods, discussed in the same paper (Table V.).

TABLE II.

Nile Floods.

	Maxima.				Minima.			
Date.	640.	900.	1160.	Mean.	640.	900.	1160.	Mean.
10	914	898	946	919	264	302	306	291
30	913	909	952	925	267	260	306	278
50	869	894	902	888	252	245	228	242
70	925	873	914	904	269	233	227	243
90	890	896	939	908	212	204	267	228
110	918	895	956	923	183	251	325	253
130	871	886	927	895	128	247	248	208
150	879	932	927	913	162	294	190	215
170	904	903	938	915	251	258	248	252
190	876	915	989	927	221	323	300	281
210	889	955	973	939	238	380	310	309
230	932	962	1021	972	317	373	323	338
250	904	953	1019	959	300	306	237	281

Here again there seems to be a long steady period followed by a comparatively sudden increase, which begins in $820+260\,n$: the period of numerous earthquakes is from 780 to 840. There seems quite a good case for connection.

6. At the 23rd meeting of the American Astronomical Society (Ann Arbor, 1919) Mr. R. E. de Lury pointed out that the 240-

year period was represented in tree growths which have apparently been traced in California for some thousands of years. Reference is made to *The Climatic Factor*, by Ellsworth Huntington—a work I have not yet seen. But Mr. de Lury quotes ten-year means for comparison with the Chinese earthquakes, and we can arrange them in the same way as Table I.

TABLE III.

Californian Tree Growths.

Date.	60.	320.	580.	840.	1100.	1360.	Mean.
10	72	68	67	64	67	73	68·5
30	67	67	67	63	67	72	67·2
50	67	67	62	67	64	70	66·2
70	68	66	61	69	64	69	66·2
90	68	63	62	67	65	69	65·7
110	67	64	63	65	67	64	65·0
130	70	63	62	66	67	65	65·5
150	72	64	61	69	66	68	66·7
170	71	64	63	75	66	70	68·2
190	70	65	62	72	65	72	67·7
210	70	64	64	68	70	72	68·0
230	68	64	64	67	76	71	68·3
250	68	66	64	68	76	74	69·3

7. The smoothness of the mean curve is quite remarkable, and the double maximum which occurs in both trees and earthquakes when arranged in 240 years disappears completely when the period is taken as 260 years. The numbers for three consecutive terms at maximum (with 240 years) are

Earthquakes . .	104	51	105
Trees . .	67·8	66·7	67·6

8 The period of 260 years seems thus in all respects preferable, save only the accordance of the harmonic phases for the earthquakes, which is a little better for 240 years. But the wave is, after all, very far from a simple harmonic wave, and this may account for the peculiarity.

9. It will be noticed that the maximum of tree growth extends from 740 to 860, a period of 120 years, including the earthquake maximum (780 to 840) but not centrally. The order is

Trees—Earthquakes—Nile.

10. Finally, it was remarked at the end of the paper on Chinese earthquakes that the period of 265 or 266 years detected in Chinese sun-spots could not be identified with the 240 years in earthquakes. But the case is now completely altered, and it seems quite possible that they are the same; in which case the cause of all these phenomena lies outside the Earth.

The Stellar Magnitude Scales of the Astrographic Catalogue. Fourteenth Note: The Perth Magnitudes for −36°, with some Remarks on Neighbouring Zones. By H. H. Turner, D.Sc., F.R.S., Savilian Professor.

1. The Perth counts for $-32°$ were given in the fifth note (*M.N.*, **75**, 144), and showed an exceptionally uniform scale. Those of $-34°$ were given in the twelfth note (*M.N.*, **78**, 584), and recently Mr. Curlewis kindly sent the counts for $-36°$, which fill the gap between Perth and Edinburgh, $-38°$ (for measures $-38°$, see *M.N.*, **78**, 587). Tables I., II., and III. below correspond with those given for $-32°$ and $-34°$.

TABLE I.

Perth Star Counts for 10 *Plates in Zone* $-36°$.

R.A. h	Brt.	A.	B.	C.	D.	E.	F.	G.	H.	J.	M.	Total.
0	19	23	29	57	81	154	150	317	267	277	563	1937
1	20	20	30	34	80	151	183	286	312	314	473	1903
2	25	22	25	18	88	150	178	310	308	302	364	1790
3	27	16	16	47	109	117	146	317	339	273	365	1772
4	13	20	24	43	90	136	171	334	391	252	376	1850
5	28	15	25	40	98	187	167	448	400	388	604	2400
6	49	41	40	57	117	202	244	513	524	523	1053	3363
7	54	49	56	109	232	326	393	747	694	857	1559	5076
8	88	62	68	197	302	648	875	1490	1827	1915	2801	10273
9	40	61	61	126	230	443	454	787	979	1209	1984	6374
10	40	33	33	80	161	329	413	772	776	790	1439	4866
11	22	37	28	69	128	220	320	488	650	545	805	3312
12	17	9	21	50	144	240	367	483	539	637	877	3384
13	36	29	56	100	173	274	361	647	686	771	1407	4540
14	17	24	20	80	160	283	343	608	675	848	1712	4770
15	24	31	34	86	159	243	304	533	636	862	1457	4369
16	29	23	27	51	114	253	327	530	786	693	1173	4006
17	73	80	77	155	288	543	803	1473	1288	2083	3982	10845
18	60	71	81	184	319	593	727	1480	1900	2079	4464	11958
19	20	19	34	71	101	256	350	723	629	864	1834	4901
20	16	30	36	54	113	230	311	607	597	687	1003	3684
21	17	26	30	80	129	269	427	638	527	581	976	3700
22	19	19	19	56	78	147	249	343	347	395	574	2246
23	13	20	20	55	103	145	232	302	347	330	553	2120
Total	766	780	890	1899	3597	6539	8495	15176	16424	18475	32398	105439

TABLE II.

Residuals of log N_0 for Perth Zone $-36°$, in units of 0·01.

R.A. h	Brt.	B.	D.	F.	H.	M.	Gal. Lat.
0	+ 1	+13	+14	+10	+10	+11	−81°
1	+ 3	+13	+ 6	+ 9	+10	+ 8	−76
2	+16	+13	+ 3	+ 5	+ 5	0	−65
3	+18	0	+ 8	− 3	− 1	− 7	−53
4	−22	− 6	− 5	− 9	− 6	−15	−41
5	+ 6	− 9	−14	−16	−14	−18	−30
6	+17	+ 5	−12	−20	−22	−21	−18
7	+10	+ 2	− 3	−13	−20	−19	− 7
8	+30	+15	+11	+10	+10	+ 8	+ 3
9	+ 1	+ 8	+ 3	− 1	− 5	− 3	+12
10	+10	− 1	− 3	− 1	− 1	− 2	+19
11	−12	− 4	− 6	− 6	− 7	−11	+24
12	−21	−31	−11	− 2	− 6	− 7	+26
13	+13	+12	+11	+ 5	+ 3	+ 5	+25
14	−26	−23	− 6	− 5	− 6	+ 1	+22
15	−18	−15	−12	−17	−20	−14	+15
16	−17	−29	−35	−31	−29	−31	+ 6
17	+22	+17	+ 8	+ 5	+ 4	+10	− 3
18	+22	+22	+20	+18	+21	+28	−14
19	−15	−11	−11	− 4	0	+ 8	−25
20	−14	+ 8	+ 5	+10	+14	+14	−37
21	− 6	+ 9	+19	+30	+28	+26	−49
22	+ 2	+ 1	+ 5	+12	+11	+10	−61
23	−19	− 3	+12	+15	+13	+12	−73

TABLE III.

Class.	log N_0.	$-\sin\theta$.	$\cos\theta$.	$\sin 2\theta$.	$\cos 2\theta$.	$\sin 3\theta$.	$\cos 3\theta$.	$\sin 4\theta$.	$\cos 4\theta$.
Brt	0·05	+·075	+·009	−·037	−·081	+·057	+·029	+·035	+·019
B	0·61	+·020	+·074	−·048	−·022	+·064	+·023	+·045	+·010
D	1·17	−·008	+·071	−·040	+·039	+·029	+·006	+·025	+·011
F	1·67	−·043	+·088	−·064	+·072	+·024	−·010	+·025	+·005
H	2·07	−·049	+·103	−·059	+·058	+·029	−·025	+·029	+·003
M	2·36	−·089	+·088	−·068	+·047	+·032	−·012	+·044	+·007
Diff.	1·59	−·087	+·032	−·023	−·006	+·008	−·033	+·023	−·006
	1·00	−·055	+·020	−·014	−·004	+·005	−·021	+·014	−·004

The first harmonic for the differences (H + M) − (D + F), reduced to unit of log N_0 in the last line, accords satisfactorily with those for the neighbouring zones, as below :—

Zone.	Measured at	First Harmonic per unit of log N_0.
−32°	Perth	−·043 cos (θ − 90°)
−34	Perth	−·061 cos (θ − 91)
−36	Perth	−·058 cos (θ − 110)
−38	Edinburgh	−·127 cos (θ − 91)
−41	Cape	−·118 cos (θ − 77)
−42	Cape	−·092 cos (θ − 106)
−43	Cape	−·043 cos (θ − 87)

The existence of *some* phenomenon worth attention is thus clear, but there is no indication of a spiral character from these particular figures. The suggested advance of the phase from Declination −32° to −43° would be 11° × 3·66 = 41°, and there is certainly no advance of this order. Indeed the phase remains sensibly constant, so that in the first instance the seven zones were associated together to form mean values for study. But reason soon appeared for separating zones −32° and −34° from the rest, as will be seen below. The mean values for the harmonics of the other five zones are given in Table IV., expressed in the form $R_n \cos(n\alpha - \theta_n)$, where α is the R.A.

TABLE IV.

Mean Coefficients of Harmonics for Zones −36° to −43°.

(The unit is 0·01.)

Perth Name.	Mean log N_0.	R_1.	θ_1.	R_2.	θ_2.	R_3.	θ_3.	R_4.	θ_4.	θ_0.
Brt	0·03	66	91°	97	219°	53	29°	69	109°	93°
B	0·67	81	64	86	236	49	36	34	60	104
D	1·04	94	56	74	292	53	70	19	21	118
F	1·60	48	26	72	248	27	77	30	80	122
H	1·99	63	346	90	238	26	108	37	59	106
M	2·38	65	299	65	226	30	110	40	60	82

The first and third phases, θ_1 and θ_3, show fairly consistent changes in opposite directions : the others may be taken as sensibly constant. We are concerned at present with the first harmonic alone, and the values of

$$\theta_0 = \theta_1 + 60° \log N_0$$

given in the last column show that a decrease of 60° per unit log N accounts for the chief part of the change in θ_1, though the relation is clearly not linear simply. Since N_0 represents the total

number of stars to an assigned brightness, and corresponds therefore to the total number in a sphere of a certain radius r, so that approximately

$$\log N_0 = 3 \log r,$$

we have

$$\theta_1 = \text{const.} - 180^\circ \log r,$$

which represents an equiangular spiral with r increasing 100 times in a revolution. [This is of course a view quite different from that previously taken, though the two may ultimately turn out to be connected.] Now, in this character zones -32° and -34° do not apparently share, so that they have been separated from the rest.

The experiment was now tried of taking the means of the residuals of the five zones, $-36^\circ, -38^\circ, -41^\circ, -42^\circ, -43^\circ$, for each group (Brt, B, . . . M); then rotating the groups through the angle $60^\circ \log N_0$, and taking the means of the six groups. The result was a fairly consistent first harmonic wave with coefficient about 0·075, and no subsidiary features of note. Comparing the mean curve with those for each group, the ratio of the coefficients to the mean value 0·075 was found to be

Group	Brt	B	D	F	H	M
Ratio	0·72	1·46	1·39	0·63	0·93	0·81

so that as a first approximation we may take the coefficient as sensibly constant for different classes of stars.

But does it vary with declination? The abrupt transition between -36°, which agrees with the zones south of it, and -34° and -32°, which do not, calls for further investigation; but the question will be answered more easily when several zones to the north are collated, including the -19° from Hyderabad just received.

The Number of Stars of Different Magnitudes in the Hyderabad Astrographic Catalogue. Third Paper: Zone -19°. By T. P. Bhaskaran, M.A.

1. In two papers in the *Monthly Notices*,* the late Director, Mr. R. J. Pocock, has given the results of a discussion of the numbers of stars of different magnitudes in the *Hyderabad Astrographic Catalogue*, vols. i. and ii. The third volume of the Catalogue, containing the diameters and measured co-ordinates of about 58,750 stars in Zone -19°, is now completed and is in the course of printing. As the plates were measured, the numbers of stars recorded under different diameters have been counted, and the results are discussed in the present note.

2. Table I. gives the cumulative totals of stars in each hour of R.A. under the headings N_{50}, N_{40}, N_{30}, N_{20}, N_{12}, and N_8 or. All,

* *Monthly Notices, R.A.S.*, 77, 432, and 78, 367.

where N_x stands for the number of stars whose recorded diameters are not less than x (the sum of two estimations is recorded in the Catalogue as the diameter of the star). As the hours of R.A. contain alternately seven and eight plates in these zones, the numbers have been multiplied by factors to make them equivalent to ten plates in each hour.

TABLE I.

Cumulative Totals for ten Plates in each hour of R.A. Zone $-19°$.

R.A. h	N_{50}.	N_{40}.	N_{30}.	N_{20}.	N_{12}.	N_8.
0	93	149	337	657	1167	1757
1	80	156	380	678	1209	1632
2	93	177	453	824	1420	1847
3	70	178	495	948	1702	2332
4	109	259	680	1356	2360	3206
5	92	231	758	1579	3141	4281
6	314	616	1376	2656	4634	6637
7	162	449	1468	3440	8095	11622
8	57	179	713	1640	3331	6079
9	59	188	520	1064	2088	2981
10	46	144	487	873	1537	2486
11	42	108	372	761	1439	2025
12	34	84	297	560	1046	1620
13	40	81	260	551	1202	1694
14	43	134	341	730	1346	1960
15	58	99	331	772	1554	2168
16	81	159	296	570	1099	1534
17	55	150	528	1254	2422	3521
18	121	249	935	2089	4135	6091
19	115	249	754	1669	3213	3836
20	56	134	663	1420	2756	2989
21	61	148	636	1238	2107	2491
22	57	124	378	897	1523	1703
23	80	171	511	930	1432	1606

3. The methods adopted for determining the magnitudes of stars in Zones $-17°$ and $-18°$ have been followed in the present zone. The magnitudes corresponding to the columns of Table I. have been formed on the Chapman and Melotte scale from the table in the *Monthly Notices*, **75**, 145. These are given in Table II., together with the magnitudes computed from the formula Mag. $= 15{\cdot}60 - 0{\cdot}92\sqrt{d}$, which is slightly different from that determined for the Zones $-17°$ and $-18°$.

TABLE II.

Diameter . .	50.	40.	30.	20.	12.	8.
C. and M. Mag.	8·91	9·70	10·84	11·65	12·42	12·84
Calculated	9·10	9·78	10·56	11·49	12·42	13·00
Difference	−·19	−·08	+·28	+·16	·00	−·16

4. Now, forming log N_γ for one square degree and clearing the results from the galactic condensation by making use of Seares's approximation, in the same way as Professor Turner has done in several papers (see *Monthly Notices*, 78, 580), we obtain log N_0 for each hour of R.A.

The mean values of log N_0 are given in Table III.; the values of the same quantity in the cases of Zones $-17°$ and $-18°$ are taken from Professor Turner's paper quoted above.

TABLE III.

Mean Values of log N_0.

(Value of *d* Hyderabad.)

	50.	40.	30.	20.	12.	8.
$-17°$	0·68	...	1·46	1·79	2·08	2·31
$-18°$	0·70	...	1·51	1·81	2·08	2·32
$-19°$	0·56	0·96	1·49	1·83	2·12	2·27

5. The residuals from the mean value of log N_0 are next formed. These are given in Table IV. in units of 0·01.

TABLE IV.

Observed Deviations of log N_0 for Hyderabad Zone $-19°$.

R.A. h	50.	40.	30.	20.	12.	8.	Gal. Lat. °
0	+32	+17	+ 7	+ 8	+ 9	+14	−81·0
1	+24	+18	+12	+ 7	+ 8	+ 9	−76·0
2	+31	+23	+18	+14	+12	+11	−63·5
3	+13	+18	+15	+13	+13	+13	−50·5
4	+27	+28	+21	+19	+17	+17	−37·5
5	+ 4	+ 7	+ 9	+ 9	+12	+10	−24·5
6	+43	+32	+15	+10	+ 7	+ 7	−11·5
7	+ 5	+ 9	+ 9	+12	+20	+20	+ 1·5
8	−31	−21	−12	− 9	− 5	+ 6	+13·5
9	−17	− 4	− 9	−10	− 9	− 8	+24·0
10	−17	− 3	+ 1	− 6	− 8	0	+33·5
11	−17	−12	− 5	− 5	− 3	− 2	+40·5
12	−26	−23	−15	−18	−17	−11	+43·0
13	−18	−24	−20	−19	−11	− 9	+41·5
14	−18	− 3	−13	−11	−10	− 8	+36·5
15	−14	−28	−26	−20	−17	−16	+28·0
16	−11	−20	−45	−49	−49	−49	+17·5
17	−40	−35	−33	−29	−29	−27	+ 6·0
18	− 5	−13	− 8	− 6	− 5	− 4	− 6·5
19	+ 8	+ 4	+ 1	+ 3	+ 4	− 3	−19·5
20	− 9	− 8	+14	+16	+18	+ 7	−32·5
21	+ 5	+ 7	+25	+23	+20	+14	−45·5
22	+ 6	+ 4	+ 7	+16	+13	+ 4	−58·5
23	+23	+22	+26	+23	+16	+ 7	−72·0
Mean log N_0	0·56	0·96	1·49	1·83	2·12	2·27	

6. Before proceeding to harmonic analysis, it may be interesting to study some broad features in these residuals. The distribution suggests that the zone may be divided into two portions R.A. $21^h - 6^h$ and R.A. $7^h - 20^h$. Now, taking the means of the residuals for the two separately, we obtain the following result:—

TABLE V.

log N_0	0·56	0·96	1·49	1·83	2·12	2·27
Portion A, R.A. $21^h - 6^h$	+21	+18	+16	+14	+13	+11
Portion B, R.A. $7^h - 20^h$	−15	−13	−12	−11	− 9	− 7
Difference	+36	+31	+28	+25	+22	+18

From the above table we see that in Portion A (R.A. $21^h - 6^h$) the residuals diminish continuously, while in Portion B (R.A. $7^h - 20^h$) they steadily increase, thus showing that the Portion A is "obscured" (*i.e.* contains fewer faint stars) relatively to Portion B.

7. Table VI. gives the results of the harmonic analysis of the residuals in Table IV.

TABLE VI.

Zone − 19°.

log N_0.	sin θ.	cos θ.	sin 2θ.	cos 2θ.	sin 3θ.	cos 3θ.	sin 4θ.	cos 4θ.
0·56	+·125	+·218	+·061	+·012	−·038	+·007	·000	+·018
0·96	+·155	+·167	+·018	+·026	−·031	−·023	−·003	−·004
1·49	+·129	+·171	−·053	+·043	−·035	−·062	+·013	−·002
1·83	+·105	+·170	−·066	+·032	−·048	−·053	+·018	−·007
2·12	+·104	+·147	−·065	+·023	−·052	−·049	+·040	−·014
2·27	+·130	+·104	−·052	+·026	−·031	−·032	+·042	−·009
3·21	−·070	−·135	−·209	+·001	−·027	−·056	+·090	−·042
1·00	−·022	−·042	−·065	·000	−·008	−·017	+·028	−·013

At the foot of the table the first three rows are subtracted from the last three, and the results are reduced to unit of log N_0 by dividing by 3·21.

8. Considering only the first harmonic, we have

sin θ.	cos θ.	R.	θ.
−·022	−·042	−·047	28°

The value θ_0 obtained from the "spiral" $\theta_0 = 247° - 3·66\,\delta$ is $247° + 70° = 317°$. The difference $\theta - \theta_0 = 71°$.

If we exclude the evidence of the brighter stars we get (by omitting the two top rows)

sin θ.	cos θ.	R.	θ.
+·000	−·084	−·083	0°

which is in better accord with the spiral value.

Nizamiah Observatory, Hyderabad:
1919 *July.*